Environmental Security Technology Certification Program

(ESTCP)

Technology Demonstration Data Report

ESTCP UXO Discrimination Study

MTADS Demonstration at Camp Sibert
Magnetometer / EM61 MkII / GEM-3 Arrays

ESTCP Project # MM-0533

Gadsden, AL

April, 2007

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14. ABSTRACT
Nova Research, Inc. conducted three total coverage surveys of the the ESTCP UXO Discrimination Study site at Site 18 of the Former Camp Sibert, AL FUDS. These surveys were conducted using the NRL MTADS magnetometer, EM61 MkII, and GEM-3 (GEMTADS) arrays. The final demonstration site was comprised of four areas totaling approximately 15 acres. A 50m x 50m geophysical prove-out area (GPO) was installed by the ESTCP Program Office using the item of interest, the 4.2-in mortar. Three additional survey areas were seeded with the item of interest prior to the demonstration. Data collection was conducted with each sensor platform in turn, starting with the GPO and then moving to the other areas. The data surrounding approximately 2,000 anomalies from each data set, selected in cooperation with the Program Office, were subjected to individual anomaly analysis and the results were used to generate the master detection anomaly list for use by data processing demonstrators. This report documents the results of this demonstration and provides an archive of the collected data sets and other generated data products.

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Abbreviations Used

Abbreviation	**Definition**
APG	Aberdeen Proving Ground
ASR	Archives Search Report
AMTADS	Airborne Multi-sensor Towed Array Detection System
CD-R	Compact Disk - Recordable
COE	(US Army) Corps of Engineers
COG	course-over-ground
DAQ	Data Acquisition (System)
DAS	Data Analysis System
DoD	Department of Defense
DSB	Defense Science Board
DVD-R	Writable digital versatile disc
ESTCP	Environmental Security Technology Certification Program
FA	False Alarm
FAR	False Alarm Rate
FQ	Fix Quality
FUDS	Formerly -Used Defense Site
GPO	Geophysical Prove-Out (area)
GPS	Global Positioning System
HASP	Health and Safety Plan
HE	High Explosive
Hz	Hertz
IDA	Institute for Defense Analyses
MM	Munitions Management
MR	Munitions Response
MTADS	Multi-sensor Towed Array Detection System
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NMEA	National Marine Electronics Association
NRL	Naval Research Laboratory
nT	nanoTesla
Pd	Probability of Detection
POC	Point of Contact
PP	Peak-to-Peak
(PTNL,)AVR	Time, Yaw, Tilt, Range for Moving Baseline RTK NMEA-0183 message
(PTNL,)GGK	Time, Position, Position Type, DOP NMEA-0183 message
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
ROC	Receiver Operating Characteristic

Abbreviations Used (Cont.)

Abbreviation	Definition
RTK	Real Time Kinematic
SHERP	Safety, Health, and Emergency Response Plan
SNR	Signal to Noise Ratio
TBD	To Be Determined
TEC	Topographic Engineering Center
USACE	United States Army Corps of Engineers
UTC	Universal Coordinated Time
UXO	Unexploded Ordnance
VHF	Very High Frequency
WAA	Wide Area Assessment
WP	White Phosphorous
YPG	Yuma Proving Ground
ZIP (250)	Iomega ZIP disk (250 MB version)

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The P.I. would like to thank Greg Nivens of Parsons for his assistance in the planning and execution of this demonstration and for acting as a liaison with the former Camp Sibert Site 18 landowners.

ABSTRACT

As part of the Environmental Security Technology Certification Program (ESTCP) Unexploded Ordnance (UXO) Discrimination Study, Nova Research, Inc. conducted three total coverage surveys of the final demonstration site for the ESTCP UXO Discrimination Study at Site 18 of the Former Camp Sibert Formerly-Used Defense Site (FUDS). These surveys were conducted using the Naval Research Laboratory (NRL) Multi-sensor Towed Array Detection System (MTADS) magnetometer, EM61 MkII, and GEM-3 (GEMTADS) arrays. The final demonstration site was comprised of four areas totaling approximately 15 acres. A 50m x 50m geophysical prove-out area (GPO) was installed by the ESTCP Program Office using the item of interest, the 4.2-in mortar. Three additional survey areas were seeded with the item of interest prior to the demonstration, labeled SouthWest, SouthEast 1, and SouthEast 2. Data collection was conducted with each sensor platform in turn, starting with the GPO and then moving to the other areas. Anomaly detection was conducted on each data set and the results provided to the Program Office along with the data archives. The data surrounding approximately 2,000 anomalies from each data set, selected in cooperation with the Program Office, were subjected to individual anomaly analysis and the results were submitted to the Program Office for use in generating the final detection anomaly list for use by the data processing demonstrators participating in the Study. This report serves to document the results of this demonstration in addition to providing an archive for the collected data sets and other generated data products.

ESTCP UXO Discrimination Study

MTADS Demonstration at Camp Sibert
Magnetometer / EM61 MkII / GEM-3 Arrays

Gadsden, AL

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1. Introduction

1.1 Background

The FY06 Defense Appropriation contained funding for the "Development of Advanced, Sophisticated, Discrimination Technologies for UXO Cleanup" in the Environmental Security Technology Certification Program. In 2003, the Defense Science Board observed: "The … problem is that instruments that can detect the buried UXOs also detect numerous scrap metal objects and other artifacts, which leads to an enormous amount of expensive digging. Typically 100 holes may be dug before a real UXO is unearthed! The Task Force assessment is that much of this wasteful digging can be eliminated by the use of more advanced technology instruments that exploit modern digital processing and advanced multi-mode sensors to achieve an improved level of discrimination of scrap from UXOs."

Significant progress has been made in discrimination technology. To date, testing of these approaches has been primarily limited to test sites with only limited application at live sites. Acceptance of discrimination technologies requires demonstration of system capabilities at real UXO sites under real world conditions. Any attempt to declare detected anomalies to be harmless and requiring no further investigation will require demonstration to regulators of not only individual technologies, but of an entire decision making process. This discrimination study will be the first phase in what is expected to be a continuing effort that will span several years.

1.2 Objective of the Demonstration

1.2.1 Objectives of the ESTCP UXO Discrimination Study

As outlined in the Environmental Security Technology Certification Program (ESTCP) Unexploded Ordnance (UXO) Discrimination Study Demonstration Plan, the objectives of the study are twofold. First, the study is designed to test and validate UXO detection and discrimination capabilities of currently available and emerging technologies on real sites under operational conditions. Second, the ESTCP Program Office and their demonstrators are investigating, in cooperation with regulators and program managers, how UXO discrimination technologies can be implemented in cleanup operations.

1.2.2 Technical objectives of the Discrimination Study

The study is designed to test and evaluate the capabilities of various UXO discrimination processes which each consist of a selected sensor hardware system, a survey mode, and a software-based processing step. These advanced methods will be compared to existing practices and will validate the pilot technologies for the following:

- Detection of UXOs
- Identification of features that can help distinguish scrap and other clutter from UXO
- Reduction of false alarms (items that could be safely left in the ground that are incorrectly classified as UXO) while maintaining acceptable P_d's
- Quantification of the cost and time impact of advanced methods on the overall cleanup process as compared to existing practices

Additionally, the study aims to understand the applicability and limitations of the selected technologies in the context of project objectives, site characteristics, and suspected ordnance contamination. Sources of uncertainty in the discrimination process will be identified and their impact quantified to support decision making. This includes issues such as the impact of data quality due to how the data are collected. The process for making the dig-no / dig decision process will be explored. Potential QA/QC processes for discrimination also will be explored. Finally, high-quality, well documented data will be collected to support the next generation of signal processing research.

1.3 Regulatory Drivers and Stakeholder Issues

ESTCP has assembled an Advisory Group to address the regulatory, programmatic, and stakeholder acceptance issues associated with the implementation of discrimination in the Munitions Response (MR) process.

1.3.1 Objective of Advisory Group

The advisory group will focus on exploring UXO discrimination processes that will be useful to regulators and site managers in making decisions by determining:

- What information is required to support a discrimination decision?
  - What data are needed to support decisions, particularly with regard to decisions not to dig all detected anomalies?
  - What are the necessary end-products to support discrimination decisions?
  - What are the site-specific factors that impact this process?
  - How best can the information be presented?

- What does the pilot project need to demonstrate for the community to consider not digging every anomaly as a viable alternative?
  - Methodology
  - Transparency
  - QA/QC requirements
  - Validation

- For implementation beyond the pilot project, how should proposals to implement a discrimination process be evaluated?

In support of the above objective, the advisory group will provide input and guidance to the Program Office on the following topics:

- Pilot project objectives and flow-down to performance metrics
- Flow-down of program objectives to data quality objectives
- Demonstration / data collection plans
- QA/QC requirements and documentation
- Interpretation, analysis, and validation
- Process flow for discrimination-based removal actions
- What does it all mean?

1.3.2 Specific Objective of Demonstration

Nova Research, Inc. conducted three total coverage surveys of the final demonstration site (15 acres, four areas). These surveys were conducted using the Naval Research Laboratory (NRL) Multi-sensor Towed Array Detection System (MTADS) magnetometer, EM61 MkII, and GEM-3 (GEMTADS) arrays. These data were collected in accordance with the overall study demonstration plan including system performance characterization including the use of emplaced calibration items and the installed geophysical prove-out area (GPO).

2. Technology Description

2.1 Technology Development and Application

The demonstration was conducted using the NRL MTADS. The MTADS has been developed with support from ESTCP. The MTADS hardware consists of a low-magnetic-signature vehicle that is used to tow the different sensor arrays over large areas (10 - 25 acres / day) to detect buried UXO. The MTADS tow vehicle and magnetometer array are shown in Figure 2-1. Positioning is provided using high performance Real Time Kinematic (RTK) Global Positioning System (GPS) receivers with position accuracies of ~5 cm. The positioning technology requires the availability of one or more known first-order survey control points. The sensor arrays are described in following sections.

2.1.1 Magnetometer Array

The MTADS magnetometer array is a linear array of eight Cs-vapor magnetometer sensors (Geometrics, Inc., G-822ROV/A). The sensors are sampled at 50 Hz and typical surveys are conducted at 6 mph. This results in a sampling density of ~6 cm down track with a cross track sensor spacing of 25 cm. The sensors are nominally mounted 25 cm above the ground. The sensor boom is designed to move up to protect the sensors from damage due to impact with obstructions. This degree of freedom allows some variation in sensor height due to surface roughness. Each magnetometer measures the local magnetic field of the earth at the sensor.

A single GPS antenna placed directly above the center of the sensor array is used to measure the sensor positions in real-time (5 Hz). All navigation and sensor data are time-stamped with Universal Coordinated Time (UTC) derived from the satellite clocks and recorded by the data acquisition computer (DAQ) in the tow vehicle. The DAQ runs the MagLogNT software package (v2.921b, Geometrics, Inc.) and the data streams from each device are recorded in separate files with a common root filename. The sensor, position, and timing files are downloaded periodically throughout a survey onto magnetic disks and transferred to the data analyst for QC / analysis. Refer to Appendix C, Section C.9.1 for file format information.

Figure 2-1 – MTADS tow vehicle and magnetometer array

2.1.2 EM61 MkII Array

The EM61 MkII MTADS array is an overlapping array of three pulsed-induction sensors specially modified by Geonics, Ltd. based on their EM61 MkII sensor with 1m x 1m sensor coils. The array configuration is shown schematically in Figure 2-2. The direction of travel for the array is indicated by the black arrows. Sensors #1 (Red) and #3 (Blue) are mounted side by side on the trailer while Sensor #2 (Green) is mounted 8 cm above and 10 cm aft of the other two sensors. Each EM61 MkII sensor is composed of a bottom coil and a top coil separate by fiberglass standoffs. The nominal ride height of the bottom coils is 33.5 cm above the ground and the top coil is mounted 43.5 cm above the bottom coil (bottom of coil to bottom of coil separation). The bottom coil is 5.5 cm tall and the top coil is 2.5 cm tall.

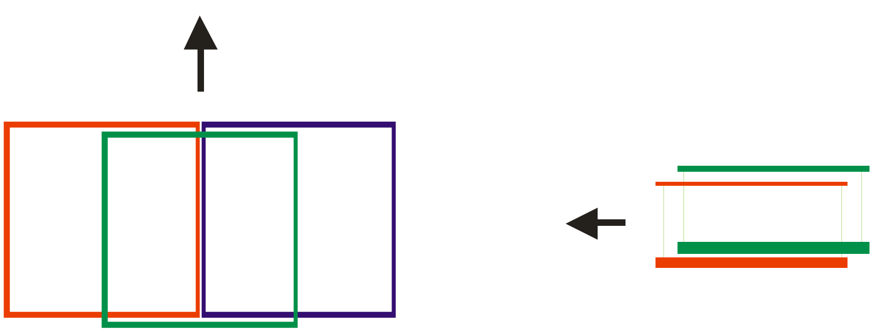

Figure 2-2 – Top and Side schematic views of the MTADS EM61 MkII array

The EM61 MkII sensors employed by MTADS have been modified to make them more compatible with vehicular survey speeds and to increase their sensitivity to small objects. The array is operated with the three transmitters synchronized to generate the largest transmit moment. The EM61 MkII sensor can be operated in one of two modes: 1) in 4 time gate mode, in which 4 time gate measurements are made for the bottom coil or 2) in Differential mode, in which 3 time gate measurements are made for the bottom coil, and one is made for the top coil. The timing of the time gates in the MTADS EM61 MkII sensors has been altered from the standard unit and the delay times are given in Table 2-1.

Table 2-1 – NRL EM61 MkII Array Gate Timing Parameters

4 Gate Mode (Bottom Coil)	Delay (μs)	Differential Mode	Delay (μs)
Gate 1	307	Bottom Gate 1	307
Gate 2	508	Top Gate 1	307
Gate 3	738	Bottom Gate 2	738
Gate 4	1000	Bottom Gate 3	1000

The notation S1 for time gate 1 and so forth are used in the remainder of this document. MTADS surveys are typically performed using the Differential mode and this mode was used for this demonstration. While the output data packet format is identical to that of the standard MkII instrument as given in the Geonics EM61 MkII manual [1], there are some important differences in the interpretation. First, as mentioned above, the time gate delay times have been altered. Second, the byte order for the time gate range factors is Gates 1,4,3,2 rather than the typical 1,2,3,4. The data channels are also presented in the order Gates 1,4,3,2. All conversions from raw counts to response in mV are given as:

$$RESPONSE = \frac{DATA\ x\ 4.8333}{RANGE}$$

The channel-specific *RANGE* values are 100, 10, or 1, as indicated in the Scale Factor parameter in the raw data packet (see Appendix C, Section C.9.2). Nominal survey speed is 3 mph and the sensor readings are recorded at 10 Hz. This results in a down-track sampling of ~15 cm and a cross-track interval of 50 cm. In order to obtain sufficient “looks” at the anomalies, or to insure illumination of all three principle axes of the anomaly with the primary field, data are collected in two orthogonal surveys. The EM61 MkII array being pulled by the MTADS tow vehicle is shown in Figure 2-3.

Individual sensors in the EM61 MkII array are located using a three-receiver RTK GPS system shown schematically in Figure 2-4 [2]. The three-receiver configuration extends the concept of RTK operations from that of a fixed base station and a moving rover to moving base stations and moving rovers. The lead GPS antenna (and receiver, MB1) receive corrections from the fixed base station at 1 Hz in the same manner as for the magnetometer MTADS. This corrected position is reported at 10-20 Hz using a vendor-specific National Marine Electronics Association (NMEA) NMEA-0183 message format (PTNL,GGK or GGK). The MB1 receiver also operates as a ‘moving base,’ transmitting corrections (by serial cable) to the next GPS receiver (MB2) which uses the corrections to operate in RTK mode.

Figure 2-3 – MTADS EM61 MkII array pulled by the MTADS tow vehicle

A vector (AVR1, heading (yaw), angle (pitch), and range) between the two antennae is reported at 10 Hz using a vendor-specific NMEA-0183 message format (PTNL,AVR or AVR). MB2 also provides 'moving base' corrections to the third GPS antenna (MR) and a second vector (AVR2) is reported at 10 Hz. All GPS measurements are recorded at full RTK precision, ~2-5 cm. All sensor readings are referenced to the GPS 1-PPS output to fully take advantage of the precision of the GPS measurements. An Inertial Measurement Unit (IMU) is also included on the sensor array to provide complementary platform orientation information. The IMU is a Crossbow VG300 running at 30 Hz.

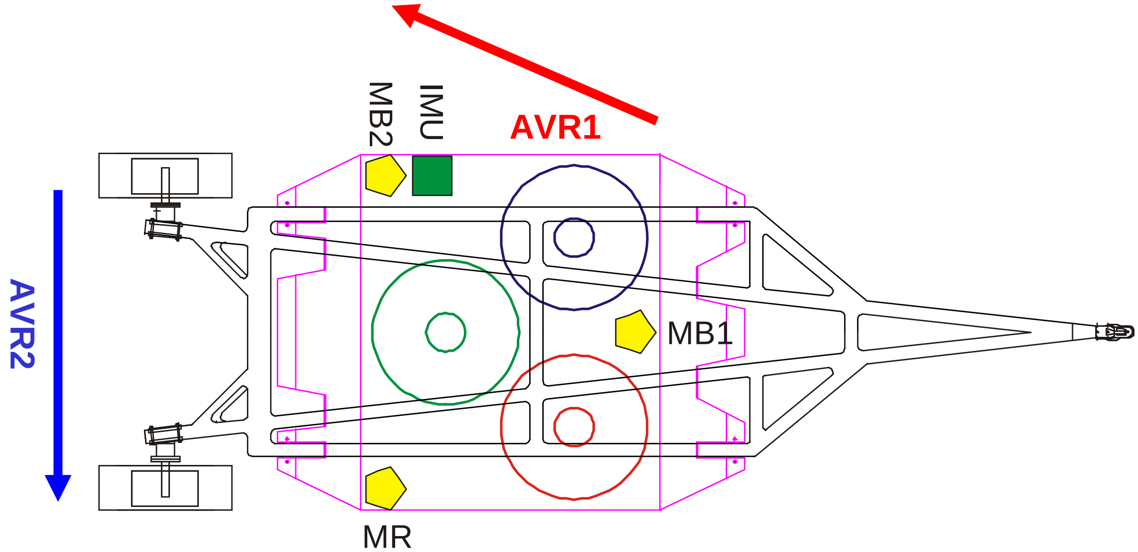

Figure 2-4 – MTADS EM trailer with approximate locations of GPS and IMU equipment indicated. The colored circles represent the GEM-3 sensors of the GEMTADS array.

A close-up view of the sensor platform is shown in Figure 2-5 which shows the three GPS antennae and the IMU (black box under the aft port GPS antenna). The airborne adjunct of the

MTADS, the AMTADS uses a similar configuration with two GPS antennae / receivers to provide the yaw and roll angles of the sensor boom and pitch from the IMU [3].

Figure 2-5 – Close-up of MTADS EM61 array with GPS and IMU

The individual data streams (sensor readings, GPS positions, times, etc.) are collected by the data acquisition computer, running the MagLogNT software package, and are each recorded in a separate file. These individual data files, which share a root name, consist of three EM61 MkII sensor data files, four GPS files (one containing the GGK and the first AVR sentences, another containing the second AVR sentence, a third containing the UTC time tag, and the fourth containing the computer time-stamped arrival of the GPS 1-PPS), and one IMU file. The EM61 MkII and IMU data files are recorded in packed binary formats. All GPS files are ASCII format. All these files are transferred to the data analyst using magnetic disks. Refer to Appendix C, Section C.9.2 for the details of the file formats.

2.1.3 GEM-3 (GEMTADS) Array

The MTADS GEM-3 array consists of three, 96-cm diameter GEM-3 sensors (Geophex, Ltd.) in a triangular configuration with two sensors across the front of the array and one centered in the rear. The nominal ride height of the sensors is 33.5 cm above the ground. The roughly 2-m square array is shown schematically in Figure 2-4. Figure 2-6 and Figure 2-7 show the configured array being pulled by the MTADS tow vehicle. The sensors have been false-colored (Red, Green, Blue) in Figure 2-6 to match the color scheme used in the other figures in this section and in the DAQ software display. The array is mounted on a rigid support which is attached to the MTADS EM trailer using non-metallic fasteners. The GPS / IMU telemetry equipment used for GEMTADS is the same as that used for the EM61 MkII array and described in the previous section.

The standard GEM-3 sensor drive electronics have been modified to produce a substantially higher transmit moment for this array. Each individual sensor can transmit a composite waveform of one to ten frequencies in the frequency range of 30 to 20,010 Hz with a base period of 1/30 sec. For this survey, a composite transmitter waveform of nine frequencies log-spaced from 90 to 20010 Hz is used. Two additional base periods are required for signal deconvolution and to output the response from each sensor. The array can therefore operate continuously with one sensor actively transmitting while the other two sensors are processing data at any given time. Allowing for a short coil settling time between the transmissions from each sensor, an effective array sampling rate of just over 9 Hz is achieved. Sequential transmitter operation also alleviates the need for the orthogonal survey mode employed for the EM61 MkII array. Coupled with our standard survey speed of 3 mph, the result is a down-track sampling spacing of ~15 cm with a cross-track spacing of 50 cm.

Figure 2-6 – MTADS GEM-3 array mounted on the EM sensor trailer. In addition to the three GEM sensors, note the three GPS antennae and the IMU for platform motion measurement.

Figure 2-7 – MTADS GEM-3 array in operation pulled by the MTADS tow vehicle

An interleaved survey pattern is used to decrease the cross-track spacing to 25 cm as depicted in Figure 2-8.

The GEM-3 sensors are controlled by a custom electronics package designed and built by Geophex, Ltd. It is mounted in an equipment rack in the MTADS tow vehicle as shown in Figure 2-9. Overall control of data collection is accomplished with a custom version of the standard GEM-3 sensor control software, WinGem2KArr, running under Windows 2000 on our data acquisition computer. An example of the working screen of this program is shown in Figure 2-10. This software package logs the data from the GEM-3 sensors, the three GPS NMEA sentences, the time of the GPS 1-PPS pulse, the GPS UTC time stamp, and the IMU data in separate files with a common base survey name. The data are periodically transferred to the data analyst for immediate QC checks and for further processing. Refer to Appendix C, Section C.9.3 for the details of the file formats.

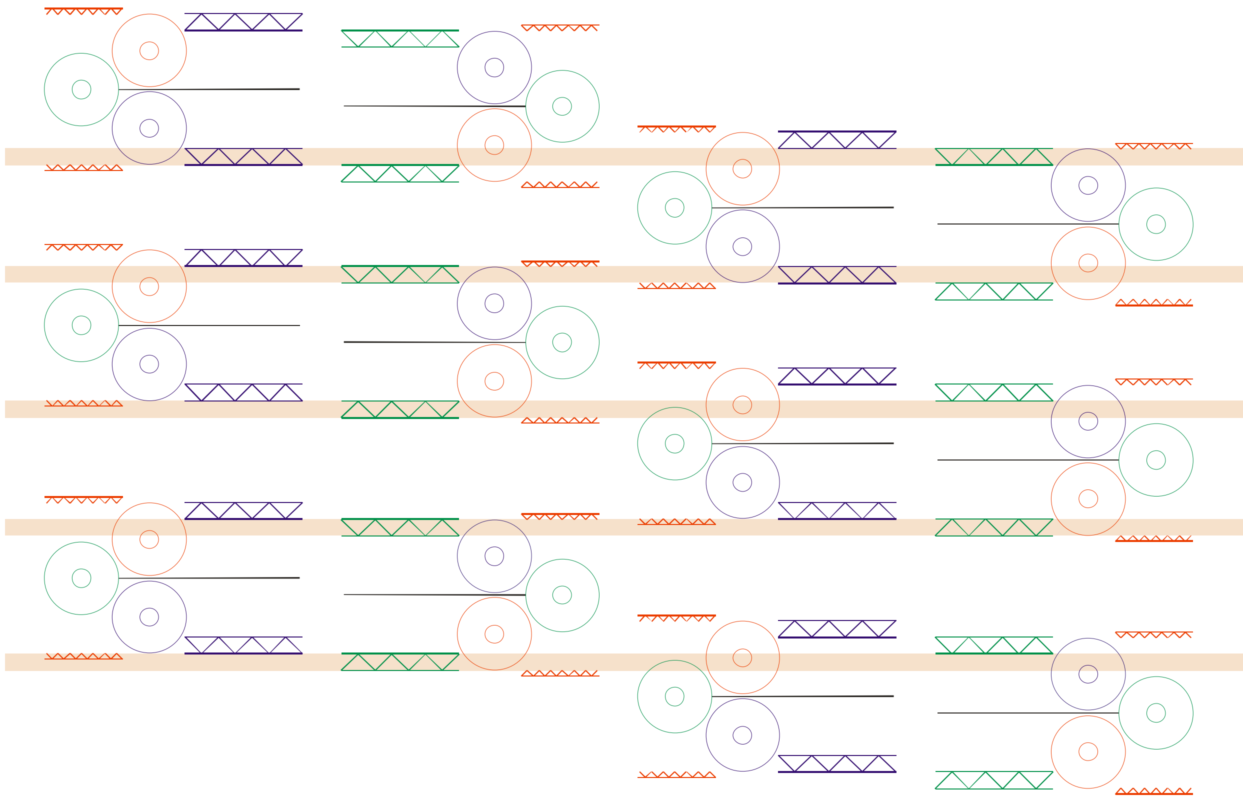

Figure 2-8 – Schematic of interleaved survey pattern for GEMTADS surveys. The sensors are depicted as colored circles. The large cross-hatched sections indicate the path of the tow vehicle tires. The outer extents of the swath of the EM trailer tires are represented by the narrow cross-hatching. The tan bars represent areas where two tire tracks are collocated.

Figure 2-9 – GEM-3 array control electronics and GPS receivers

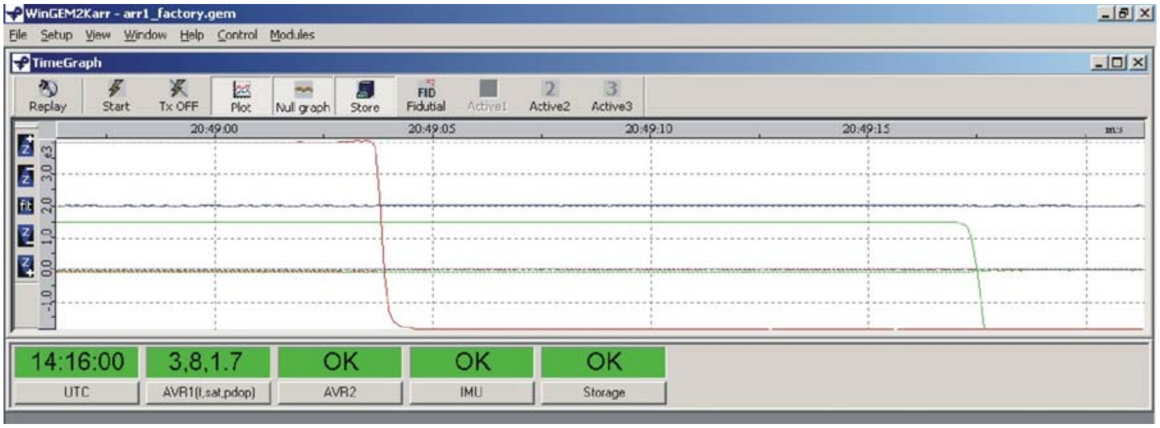

Figure 2-10 – Working screen of the WinGEM2kArr program

2.1.4 Pilot Guidance System

The GPS positioning information used for data collection is shared with an onboard navigation guidance display and provides real-time navigational information to the operator. The guidance display was originally developed for the airborne adjunct of the MTADS system (AMTADS) [3] and is installed in the vehicle and available for the operator to use. Figure 2-11 shows a screenshot of the guidance display configured for vehicular use.

An integral part of the guidance display is the ability to import a series of planned survey lines (or transects) and to guide the operator to follow these transects. In the context of this demonstration, the pilot guidance display can be used to guide the operator to the survey area and provide immediate feedback on progress and data coverage. The display provides a left-right course correction indicator, an optional altitude indicator for aircraft applications, and color-coded flight swath overlays where the current transect is displayed in red and the other transects are displayed in black for operator reference. The survey course-over-ground (COG) is plotted for the operator in real time on the display. The COG plot is color-coded based on the RTK GPS system status. When fully operational, the COG plot is color-coded green. If the system status is degraded, the COG plot color changes from green to yellow to red (based on severity) to warn the operator and allow for on-the-fly reacquisition of the affected area. Figure 2-11 shows the operator surveying line 30 of a transect plan.

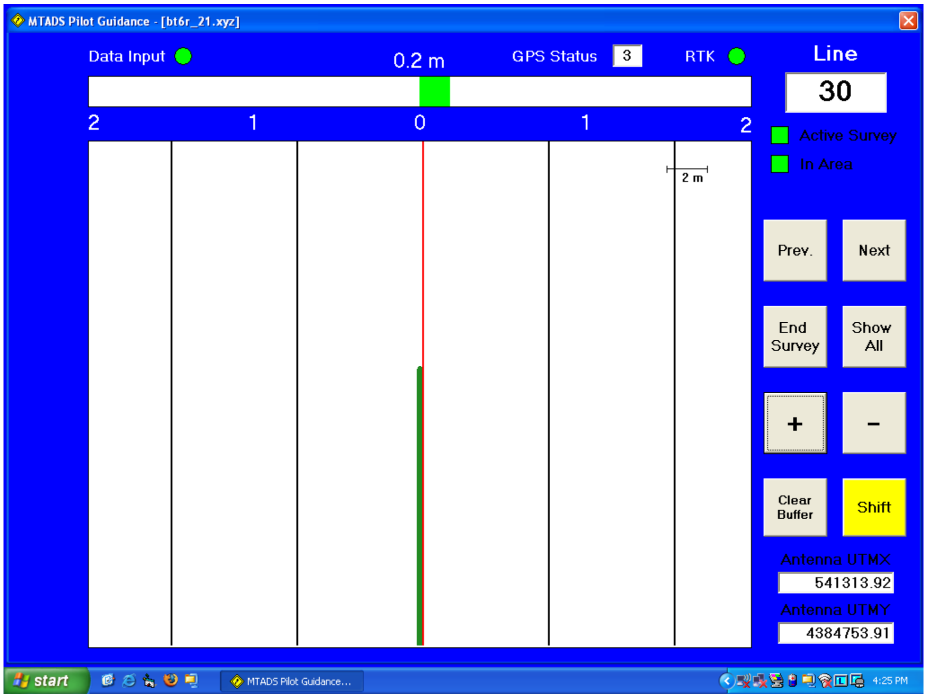

Figure 2-11 – Screenshot of MTADS Pilot Guidance Display

2.1.5 Data Analysis Methodology

2.1.5.1 Magnetometer Array

Each data set is collected using the MagLogNT software package. The collected raw data are preprocessed on site for quality assurance purposes using standard MTADS procedures and checks. The data set is comprised of ten separate files, each containing the data from a single system device. See Appendix C, Section C.9.1 for further details about file contents and formats. Each device has a unique data rate. A software package written by NRL examines each file and compares the number of entries to the product (total survey time * data rate). Any discrepancies are flagged for the Data Analyst to address. Next, the data are merged and imported into a single Oasis montaj (v6.4, Geosoft, Inc.) database using custom scripts developed from the original MTADS DAS routines which have been extensively validated. An example of a working screen from Oasis montaj is shown in Figure 2-12. As part of the import process any data corresponding to a magnetometer outage, a GPS outage, or a vehicle stop / reverse, is defaulted or marked to not be further processed. Defaulted data are not deleted and can be recovered at a later time if so desired. Any long wavelength features such as the diurnal variation of the Earth's magnetic field and large scale geology are filtered from the data (demedianed). The located demedianed magnetometer data can then be exported into a variety of GIS-compatible formats for delivery and archival purposes. All anomalies above the selected threshold are then identified and an anomaly list generated. The details of the threshold selection process are given in Section 3.2.6.

The located, demedianed magnetometer data are then imported into the MTADS Data Analysis System (DAS) software (or the equivalent UX-Analyze). The data surrounding the center of each selected anomaly are extracted and submitted to the physics-based models resident in the MTADS DAS to determine anomaly size, position, and depth. A spreadsheet (Excel 2003, Microsoft, Inc.) containing details of the anomaly location and fit parameters is then provided. The located demedianed magnetometer data are also provided as a deliverable.

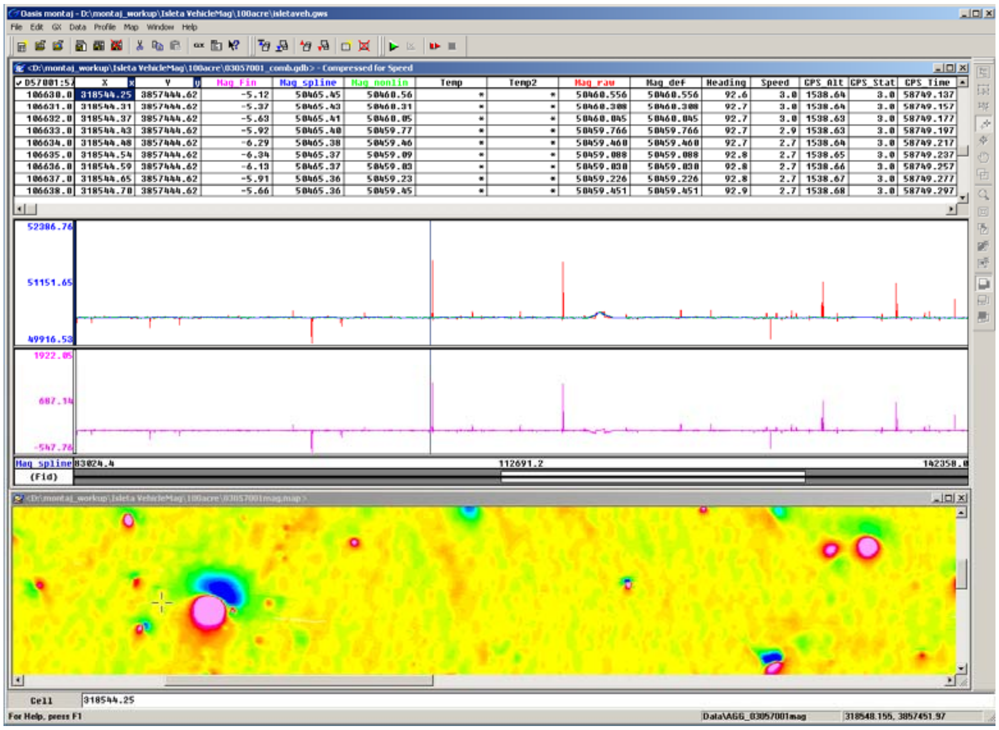

Figure 2-12 – Working screen in Oasis montaj™ of data preprocessing work flow

2.1.5.2 EM61 MkII Array

Similar to the magnetometer array, each data set is collected using the MagLogNT software package. The collected raw data are preprocessed on site for quality assurance purposes using standard MTADS procedures and checks. The data set is comprised of thirteen separate files, each containing the data from a single system device. See Appendix C, Section C.9.2 for further details about file contents and formats. Each device has a unique data rate. During the data import phase of the QC process, software written by SAIC computes the average data rate for each file as the file is being processed. Any discrepancies are flagged for the Data Analyst to address. After the data import and QC phase, the data are transferred to Oasis montaj to locate and map the data. As part of the import process any data corresponding to a sensor outage, a GPS outage, or a vehicle stop / reverse, is defaulted or marked to not be further processed. Defaulted data are not deleted and can be recovered at a later time if so desired. Any long wavelength features such as sensor drift and large scale geology are filtered from the data (demedianed). Once data collection for an area is complete, all associated data are assembled into a final data store (Geosoft database). The two orthogonal survey data sets are merged and anomalies are selected using the determined threshold. The details of the threshold selection process are given in Section 3.2.6. The located, demedianed EM61 MkII data and the anomaly details (location, magnitude) are provided as deliverables.

The data (position, orientation, and sensor data for 4 time gates) surrounding the center of each selected anomaly are extracted and submitted to the physics-based models resident in the Oasis montaj expansion module UX-Analyze, an equivalent to the MTADS DAS, to determine anomaly size & shape, position, and depth for an equivalent sphere. It is possible to treat the anomaly as either ferrous or non-ferrous in this analysis, potentially yielding different size and depth responses. The responses in both cases are determined and reported. A spreadsheet (Excel 2003, Microsoft, Inc.) containing details of the anomaly location and fit parameters are then provided.

2.1.5.3 GEM-3 (GEMTADS) Array

Each data set is collected using the WinGem2KArr software package. The collected raw data are preprocessed on site for quality assurance purposes using standard MTADS procedures and checks. The data set is comprised of eight separate files, each containing the data from a single system device. See Appendix C, Section C.9.3 for further details about file contents and formats. Each device has a unique data rate. During the data import phase of the QC process, software written by SAIC computes the average data rate for each file as the file is being processed. Any discrepancies are flagged for the Data Analyst to address. After the data import and QC phase, the data are transferred to Oasis montaj to locate and map the data. As part of the import process any data corresponding to a sensor outage, a GPS outage, or a vehicle stop / reverse, is defaulted or marked to not be further processed. Defaulted data are not deleted and can be recovered at a later time if so desired. Any long wavelength features such as sensor drift and large scale geology are filtered from the data (demedianed). Once data collection for an area is complete, all associated data are assembled into a final data store (Geosoft database). All anomalies above the selected threshold are identified and an anomaly list generated. The details of the threshold selection process are given in Section 3.2.6. The located, demedianed GEMTADS data and the anomaly details (location, magnitude) are provided as deliverables.

The located demedianed GEMTADS data (position, orientation, and 9 data pairs (In-phase and Quadrature response for 9 transmit frequencies)) surrounding the center of each selected anomaly are extracted and submitted to a physics-based model resident in the MTADS DAS to determine the position, depth and frequency-dependent betas of an object that would produce the anomaly in question. The betas are the principal components of the induced magnetization tensor. The size of an equivalent sphere is also estimated from the betas via established parametric models. A spreadsheet (Excel 2003, Microsoft, Inc.) containing details of the anomaly locations and fit parameters has been provided.

2.2 Previous Testing of the Technology

The Chemistry Division of the Naval Research Laboratory has participated in several programs funded by SERDP and ESTCP whose goal has been to enhance the discrimination ability of MTADS for both the magnetometer and EM-61 array configurations. The process was based on making use of both the location information inherent in an item’s magnetometry response and the shape and size information inherent in the response to the time-domain electromagnetic induction (EMI) sensors that are part of the baseline MTADS in either a cooperative or joint inversion. As part of ESTCP Project 199812, a demonstration was conducted on a live-fire range, the ‘L’ Range at the Army Research Laboratory’s Blossom Point Facility [4]. In 2001, a second demonstration was conducted at the Impact Area of the Badlands Bombing Range, SD [5] as part of ESTCP Project 4003. In all these efforts, our classification ability has been limited by the information available from the time-domain EMI sensor. The EM61 is a time-domain instrument with either a single gate to sample the amplitude of the decaying signal (MkI) or four gates relatively early in time (MkII). The first generation of the MTADS EM61 MkII array was demonstrated in 2001 [5] at the Badlands Bombing Range, SD with little demonstrable gain over the single decay of the MkI array. A second generation of the MkII array with updated electronics was constructed in 2003 as part of ESTCP Project 200413. The upgraded MTADS EM61 MkII array was demonstrated at both of the Standardized UXO Technology Demonstration Sites located at the Aberdeen and Yuma Test Centers in 2003 and 2004 [6]. Appendix A summarizes the Open Field scenario results of the APG demonstration. The Response stage results for the EM61 MkII Array from the APG Open Field Scenario are shown in Figure 2-13 broken out by munitions type. The depth of 100% detection is denoted by the blue bar and the depth of maximum detection is shown as the horizontal line. For some of the items, the 105-mm HEAT for example, these two depths are the same. For many of the items, the maximum depth of detection is below the depth of 100% detection.

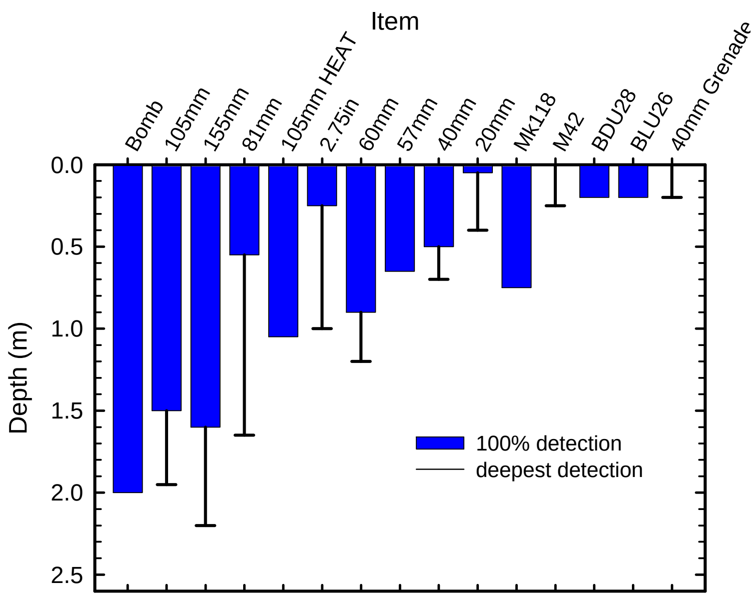

Figure 2-13 – MTADS EM61 MkII response stage results for the APG Open Field scenario broken out by munitions type

The MTADS EM61 MkII Discrimination Stage results from the APG Open Field are shown in Figure 2-14. The results are analyzed by excluding first items that were not covered by the survey or were within 2-m of another item and then further excluding items deeper than 11x their diameter. The exclusion of items at depths below 11x their diameter (presumably lower S/N anomalies) somewhat improves the discrimination performance. The 11x diameter rule is referenced in the Figure as ‘COE.’

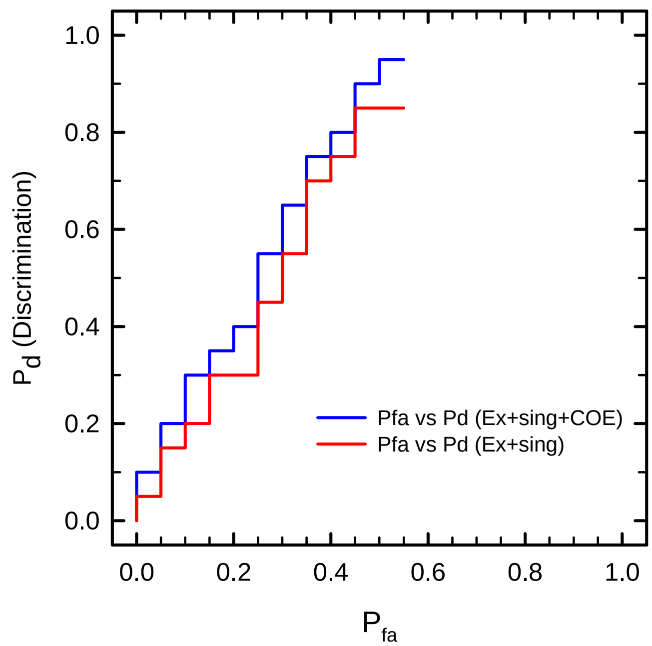

Figure 2-14 – MTADS EM61 MkII discrimination performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

To make further progress on UXO discrimination, a sensor with more available information was required. The Geophex, Ltd. GEM-3 sensor is a frequency-domain EMI sensor with up to ten transmit frequencies available for simultaneous measurement of the in-phase and quadrature response of the target. In principle, there will be much more information available from a GEM-3 sensor for use in discrimination decisions. However, the commercial GEM-3 sensor is a hand-held instrument with relatively slow data rates and is thus not very amenable to rapid, wide area surveys.

ESTCP Project MM-0033, Enhanced UXO Discrimination Using Frequency-Domain Electromagnetic Induction, was funded to overcome this limitation by integrating an array of GEM-3 sensors with the MTADS platform [7]. The project objective was to demonstrate the optimum system built around the GEM-3 sensor that delivers the most discrimination performance while retaining acceptable survey efficiency. A three-sensor array system was designed around a modified GEM-3 sensor. The system was built and characterized in 2002 and 2003 and then demonstrated at the Standardized UXO Demonstration sites at Aberdeen Proving Ground and Yuma Proving Ground in 2003 and 2004 [6]. At each of the sites, the Calibration Lanes, the Blind Test Grid, and as much of the Open Field Area as was possible were surveyed. For the Blind Test Grid and the Open Field, the ranked target picks were submitted to the Aberdeen Test Center for scoring. Appendix B summarizing the performance of the GEMTADS array at both sites as reported in Reference 7. Response stage results broken out by munitions type are shown in Figure 2-15. For the majority of the items, the maximum depth of detection is below the depth of 100% detection.

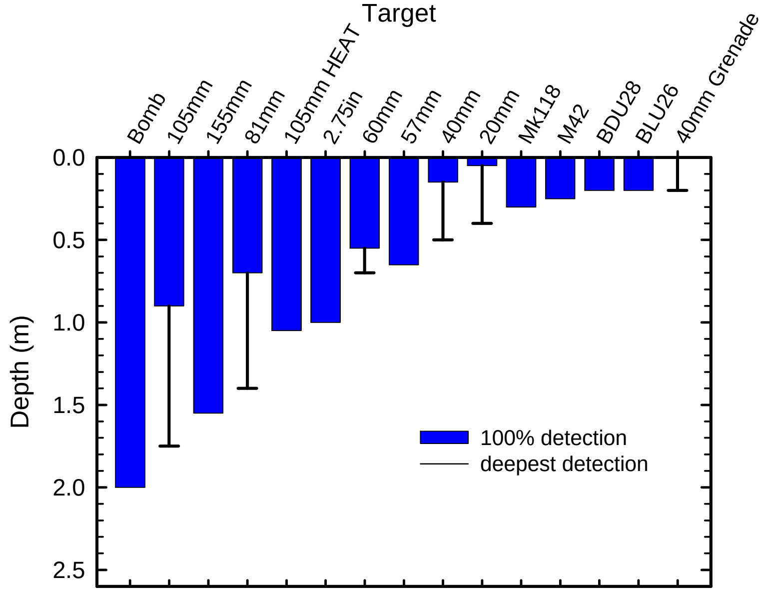

Figure 2-15 – GEMTADS response stage results for the APG Open Field scenario broken out by target type

Discrimination stage performance at the APG Open Field using the same two analysis models is shown in Figure 2-16. As above, the exclusion of items at depths below 11x their diameter (presumably lower S/N anomalies) improves the discrimination performance obtained.

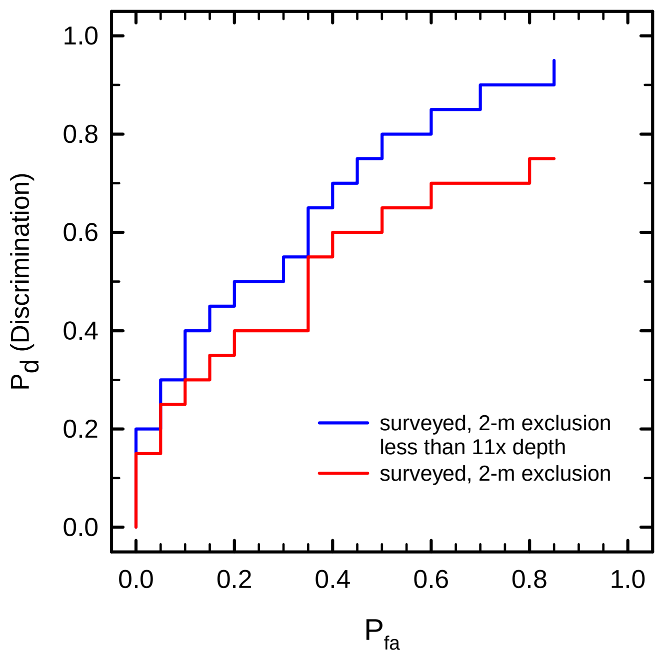

Figure 2-16 – GEMTADS discrimination performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

Reference 6 compares the detection-only performance of the magnetometer, the second-generation MTADS EM61 MkII, and the GEMTADS arrays to other demonstrators at both of the Standardized UXO Technology Demonstration Sites. All three sensor arrays were also demonstrated in the Spring of 2007 as part of the ESTCP UXO Discrimination Study at the Former Camp Sibert [8]. Data processing and the development of performance results for the various discrimination methodologies of the UXO Discrimination Study are currently ongoing.

The MTADS magnetometer array has been demonstrated at several seeded and live ranges sites over the last decade [9-14]. The MTADS magnetometer array has been selected previously to serve as the ground truth for several ESTCP-supported demonstrations [3,15,16]. The performance of the MTADS magnetometer array at a recent demonstration is documenting in Reference 16.

2.3 Advantages and Limitations of the Technology

On large open ranges the vehicular MTADS provides an efficient survey technology. Surveys with the magnetometer array often exceed production rates of 20 acres per day. Production rates for the EM systems are approximately one quarter that of the magnetometer system to maintain a sufficiently high data density. The survey speed is one half of that for the magnetometer system and to maintain data density, a second pass (orthogonal or interleaved) is required, halving the production again. UXO items with gauges larger than 20mm are typically detected to their likely burial depths. To reliably detect the smaller gauge munitions in this spectrum, the EM61 MkII array should be used rather than the magnetometer or GEM-3 arrays. Typically a human operator manually selects the data corresponding to individual anomalies. Each data segment is then processed by a physics-based algorithm incorporated into the MTADS Data Analysis System (DAS) software or an equivalent. For this demonstration, anomalies that exceeded the sensor-specific detection threshold for each data set were identified and a subset of the anomalies from each sensor system selected for further analysis. The data surrounding each selected anomaly center was then extracted and submitted to the physics-based models resident in the MTADS DAS or an equivalent.

The presence of certain terrain features such as deep ravines without good crossing points, thick clusters of trees, and other non-navigable features such as steep hill faces can limit the areas that can be surveyed. The presence of long barbed-wire fences without gates and deep ravines, steep hill and plateau faces without good access points can also slow survey operations by reducing survey line length and increasing travel time to traverse these obstacles. In the case of this demonstration, different obstacles to productivity presented themselves in terms of site access and weather conditions. The impact on the overall demonstration schedule was however, minimal.

3. Demonstration Design

3.1 Performance Objectives

Performance objectives for the demonstration are given in Table 3-1 to provide a basis for evaluating the performance and costs of the demonstrated technology. These objectives are for the technologies being demonstrated only. Overall project objectives will be given in the overall demonstration plan generated by ESTCP. The final column, 'Actual Performance Objective Met?' is added to Table 4-1 in the discussion in Section 4.1.

3.2 Testing and Evaluation Plan

3.2.1 Demonstration Set-Up and Start-Up

The Camp Sibert ESTCP UXO Discrimination Study Demonstration site is located southwest of Gadsen, AL within the boundaries of Site 18 of the former Camp Sibert FUDS site. Information on the Camp Sibert FUDS is available in the archival literature such as an Archives Search Report (ASR) developed in 1993 [17]. The former Camp Sibert is located in the Canoe Creek Valley between Chandler Mountain and Red Mountain to the northwest, and Dunaway Mountain and Canoe Creek Mountain to the southeast. Camp Sibert is comprised mainly of sparsely inhabited farmland and woodlands and encompasses approximately 37,035 acres. The City of Gadsden is growing towards the former camp boundaries from the north. The Gadsden Municipal Airport occupies the former Army airfield in the northern portion of the site.

The area that became Camp Sibert was selected in the spring of 1942 for use in the development of a Replacement Training Center (RTC) for the Army Chemical Warfare Service. The RTC was moved from Edgewood, Maryland to Alabama in the summer of 1942. In the fall of 1942, the Unit Training Center (UTC) was added as a second command. Units and individual replacements were trained in aspects of both basic military training and in the use of chemical

Table 3-1 – Performance Objectives/Metrics and Confirmation Methods

Type of Performance Objective	Performance Criteria	Expected Performance (Metric)	Performance Confirmation Method
Qualitative	*Reliability and Robustness*	*General Observations*	*Operator feedback and recording of system downtime (length and cause)*
Quantitative	*Survey Rate*	*Varies with sensor array, 5 (EM) – 20 (Mag) acres / day*	*Calculated from survey results*
	Data Density	*> 30 pts / m^2*	*Calculated from survey results*
	Percentage of Assigned Coverage Completed	*100% as allowed by topography / vegetation*	*Calculated from survey results*
	Location of Modeled Anomalies	*Horizontal: < ± 0.15 m Vertical: < 30% for depths ≥ 30 cm, < ± 0.15 m depths < 30 cm*	*Comparison of model results to known data on emplaced items or validation data on remediated items*
	Detection of GPO items of interest to depth of interest using determined thresholds	*100%*	*Comparison of anomaly lists from GPO to GPO ground truth for each sensor array*
	Signal to Noise Ratio (SNR) for Calibration Items	*+/- 10% of expected from Standardized UXO Technology Demonstration Site Performance*	*Comparison of calibration items and/or GPO results to documented Standardized UXO Technology Demonstration Site performance*
	Data throughput	*All data QC'ed in real time and results (data and anomaly analysis) provided as required by Program Office*	*Analysis of records kept / log files generated while in the field and recorded delivery times*

weapons, decontamination procedures, and smoke operations from late 1942 to early 1945. Mustard, phosgene, and possibly other agents were used in the training. This facility provided a previously unavailable opportunity for large scale training with chemical agent. Conventional weapons training was also conducted with several types and calibers fired, with the 4.2-in mortar being the heavy weapon used most in training.

The US Army also constructed an airfield for the simulation of chemical air attacks against troops. The camp was closed at the end of the war in 1945, and the chemical school transferred to Ft. McClellan, Alabama. The U.S. Army Technical Escort Unit (TEU) undertook several cleanup operations during 1947 and 1948; however, conventional ordnance may still exist in several locations. After decontamination of various ranges and toxic areas in 1948, the land was declared excess and transferred to private and local government ownership. A number of investigations have been conducted on various areas of the former Camp Sibert from 1990 to present. These investigations included record searches, interviews, surface assessments, geophysical surveys, and intrusive activities.

The ESTCP UXO Discrimination Study Demonstration Site is located within the confines of Site #18, Japanese Pillbox Area No. 2, of the former Camp Sibert FUDS. Simulated pillbox fortifications were attacked first with white phosphorous (WP) ammunition in the 4.2-in chemical mortars followed by troop advance and another volley of high explosive (HE)-filled 4.2-in mortars. Assault troops would then attack the pillboxes using machine guns, flamethrowers, and grenades. The locations of nine possible bunkers and one trench in 1943 were identified as part of the 1999 Topographic Engineering Center (TEC) investigation. There is historical evidence of intact 4.2-in mortars and 4.2-in mortar debris being found at the site. As part of the recent investigations, a limited geophysical survey of Site 18 has been conducted and multiple anomalies were identified.

The MTADS vehicular system was previously mobilized to the Demonstration Site in a U.S. Navy-owned 53-ft trailer for the initial magnetometer demonstration of the ESTCP UXO Discrimination Study [18]. Some essential support services are available on-site. Accordingly, Nova Research made provisions to acquire the remaining requisite supplies, materials, and facilities from appropriate vendors. Office space was available for use in an office trailer approximately 5 miles from the demonstration site on Pineview Circle as part of ongoing operations at the former Camp Sibert. This trailer is provided with full facilities. The office space was not used. The tow vehicle, the sensors and sensor trailers, notebook computers for the analysis team, GPS equipment, batteries and chargers, office equipment, radios and chargers, tools, equipment spares, and maintenance items, and sensors were stored on site in the 53’ trailer or in the 40’ shipping container or connex. The connex, which can be fully opened from either end for drive-through access, was used to garage and for secure storage of the MTADS vehicle and sensor platform. The 40’ shipping container and the 53’ trailer were placed at the demonstration site for ready access. Power to the trailers at the demonstration site was available on site. This power was used to recharge the vehicle, radios, and GPS batteries overnight. Communications among on-site personnel was provided by hand-held VHF radios. Radios were provided to all field and office personnel. Additional radios were provided on an as-needed basis to other teams operating on site to allow for proper coordination of safety issues. The availability of cellular phone communications was generally good throughout the site. Portable toilets were provided by Parsons under an existing contract to support all field crews with weekly servicing.

The site is located approximately 50 miles northwest of the Birmingham Regional Airport or 86 miles southeast of the Huntsville International Airport. The site is near Interstate 59 Exit 181 in Gadsden and located approximately 8 miles southwest of the City of Gadsden, near the Gadsden Municipal Airport. The approximate coordinates for Site 18 are given in Table 3-2. Figure 3-1 shows the site boundaries and the four survey areas that comprised the final demonstration site. The site boundary is shown in pink and the survey area boundaries are shown in brown. The boundary coordinates of the four survey areas are given in Table 3-3. The four survey areas encompass approximately 15 acres. There are five GPS control points available in and near Site 18. The details are listed in Table 3-4 and the three control points that are located within Site 18 are shown in Figure 3-1 as open orange circles with point names indicated above. The control point “Site8 Base” is 1.7 km northwest of the site, possible along the road leaving the site in that direction. Control Points 354 and 355 are approximately 200 m northeast of the northern edge of the area shown in Figure 3-1 along the road leaving the site to the northeast.

Table 3-2 – Coordinates for the Approximate Corners of Site 18 of the former Camp Sibert FUDS

Point	Latitude	Longitude	Northing (m)	Easting (m)	Northing (US ft)	Easting (US ft)
	NAD83		UTM Zone 16N, NAD 83		Alabama State Plane East, NAD83	
SW	33º 53' 49.82182" N	86º 09' 27.42312" W	3,751,074.122	577,886.874	1,236,041.583	557,761.883
NW	33º 54' 30.12076" N	86º 09' 27.57570" W	3,752,315.306	577,872.776	1,240,115.173	557,761.883
NE	33º 54' 30.25275" N	86º 08' 36.32468" W	3,752,330.258	579,188.907	1,240,115.173	562,081.442
SE	33º 53' 49.95375" N	86º 08' 36.17879" W	3,751,089.069	579,203.005	1,236,041.583	562,081.442

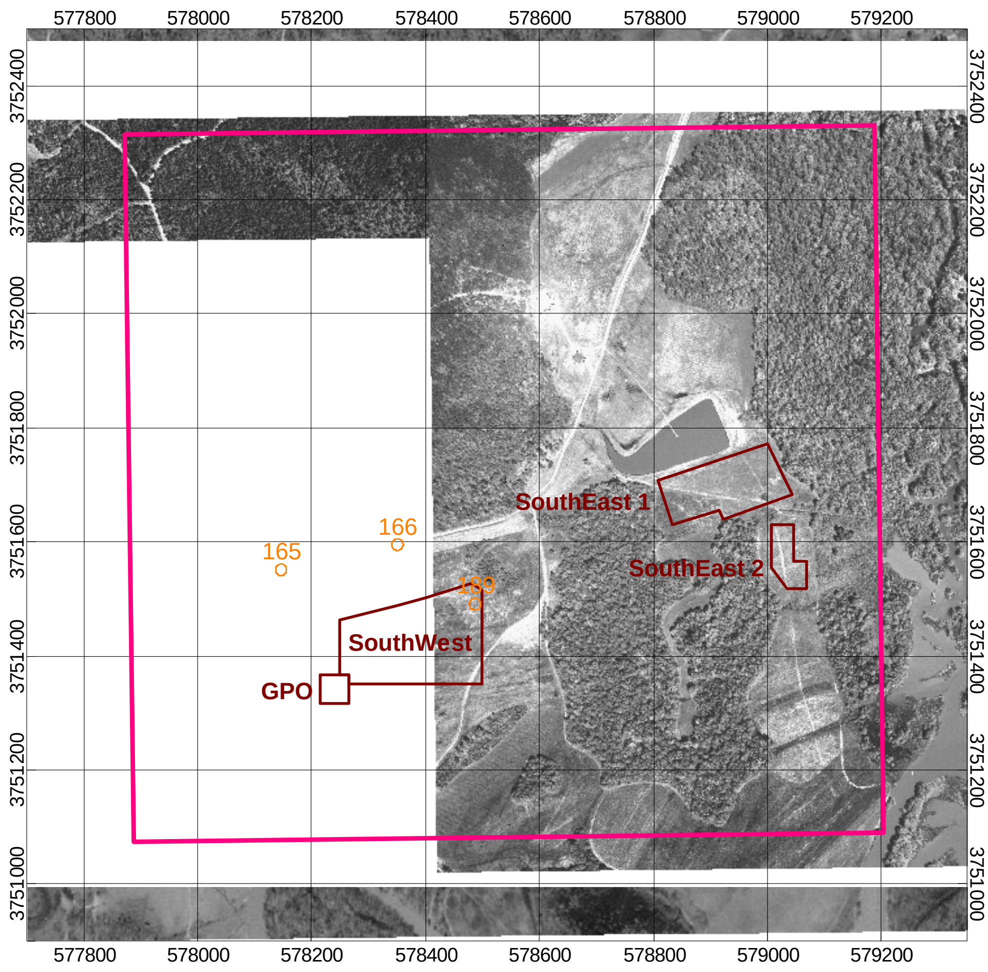

Figure 3-1 – The four survey areas comprising the ESTCP UXO Discrimination Study site within the former Camp Sibert FUDS. Individual areas are identified as labeled in the figure. Three available control points within the site are indicated as open orange circles with the point name above.

Table 3-3 – Final boundaries for ESTCP UXO Discrimination Study

UTM Zone 16N (meters)		**UTM Zone 16N (meters)**	
Easting	**Northing**	**Easting**	**Northing**
GPO (GPO)		**SouthWest (SW)**	
578,266	3,751,366	578,250	3,751,463
578,266	3,751,316	578,250	3,751,366
578,216	3,751,316	578,266	3,751,366
578,216	3,751,366	578,266	3,751,350
SouthEast 1 (SE1)		578,500	3,751,350
578,807	3,751,707	578,500	3,751,516
578,833	3,751,629	578,481	3,751,526
578,915	3,751,655	578,400	3,751,503
578,923	3,751,640	578,350	3,751,489
579,043	3,751,682	578,286	3,751,472
579,000	3,751,771		
SouthEast 2 (SE2)			
579,007	3,751,630		
579,007	3,751,555		
579,035	3,751,518		
579,070	3,751,518		
579,070	3,751,566		
579,046	3,751,566		
579,046	3,751,630		

Table 3-4 – Available Survey Control Points in the Vicinity of Site 18 of the former Camp Sibert FUDS

Point	**Latitude**	**Longitude**	**Northing (m)**	**Easting (m)**	**Northing (US ft)**	**Easting (US ft)**
	NAD83		**UTM Zone 16N, NAD 83**		**Alabama State Plane East, NAD83**	
Site8 Base	33º 55’ 17.29002” N	86º 09’ 58.28649” W	3,753,761.696	577,072.302	1,244,891.487	555,188.983
165	33º 54’ 05.22848” N	86º 09’ 17.17042” W	3,751,550.813	578,146.300	1,237,596.221	558,630.983
166	33º 54’ 06.61350” N	86º 09’ 09.19992” W	3,751,595.159	578,350.654	1,237,734.129	559,303.239
189	33º 54’ 03.19413” N	86º 09’ 03.92590” W	3,751,490.960	578,486.975	1,237,387.109	559,746.706
354	33º 54’ 39.30301” N	86º 08’ 39.26633” W	3,752,608.379	579,111.040	1,241,030.753	561,836.285
355	33º 54’ 39.99249” N	86º 08’ 36.07590” W	3,752,630.298	579,192.793	1,241,099.635	562,105.381

Control Point 189 was used exclusively for the initial magnetometer demonstration and also for this demonstration. The vertical control for control point 189 was established during the initial magnetometer demonstration using the “HERE” averaging feature of our GPS base station as 134.835 m HAE. Control point 189 was established two years ago by Parson’s surveying contractor using a base station point located in Birmingham, AL. Additional control points 823, 824, and 825 were installed near control point 189 by Parson’s surveying contractor to alleviate potential overlapping usage of control point 189 during this demonstration. These additional control points were emplaced using the survey contractor’s new base station point in Ashville, AL, which is closer to the site. As other data collection teams made use of these additional points, data registration discrepancies were uncovered. The contractor was called back to measure the position of control point 189 using the current control. Both the old and new positions are given in Table 3-5 below. The current understanding is that either a) the difference arises from the different base station points that were used as references or that b) the survey marker of control point 189, a piece of rebar) was inadvertently moved since it was emplaced but prior to the initial magnetometer demonstration. As a majority of the data collected at Site 18 was collected using the original coordinates of control point 189, it is recommended that the positions recorded for any data collected using the 820-series control points be shifted to the original control point 189 reference.

Table 3-5 – Control Point 189 Position Discrepancies and 820-Series Control Points

Point	Latitude	Longitude	Northing (m)	Easting (m)	Northing (US ft)	Easting (US ft)	Elevation* (m)
	NAD83		UTM Zone 16N, NAD 83		Alabama State Plane East, NAD83		
189 Orig.	33º 54’ 03.19413” N	86º 09’ 03.92590” W	3,751,490.960	578,486.975	1,237,387.109	559,746.706	N/A
189 New	33º 54’ 03.18692” N	86º 09’ 03.92145” W	3,751,490.739	578,487.091	1,237,386.380	559,747.079	N/A
Diff. (O-N)			0.221	-0.116	0.729	-0.373	
823	33º 54’ 03.16626” N	86º 09’ 02.98122” W	3,751,490.302	578,511.244	1,237,384.046	559,826.323	167.618
824	33º 54’ 03.76307” N	86º 09’ 4.49410” W	3,751,508.363	578,472.237	1,237,444.768	559,698.992	167.452
825	33º 54’ 11.87448” N	86º 08’ 46.53468” W	3,751,762.019	578,931.412	1,238,260.047	561,215.267	158.269

* No datum or geoid was specified by the surveyor for the elevations. NAVD88 / Geoid03 is a commonly used reference.

Upon arrival, the team personnel removed the MTADS tow vehicle and magnetometer array from the connex and set up for field operations. The coordinates of the provided geodetic control points are given in Table 3-4 (horizontal datum: North American Datum of 1983 (NAD83)). The RTK GPS base station receiver and radio link were established on control point 189. The magnetometer trailer with the magnetometers was connected to the tow vehicle and the system was powered up. The connectivity of the sensors to the DAQ computer and the establishment of normal SNR performance was verified along with the operational state of the vehicle RTK system. Details of the standard MTADS calibration diagnostics are given in Section 3.2.2.1. These data were collected and submitted to the Data Analyst for validation. These tests were repeated throughout the survey campaign as directed by the QAO. This procedure is modified to account for the different requirements of each sensor platform as detailed in Section 3.2.2.1.

When all system checks were completed to the satisfaction of the QAO, the required systems characterization/calibration measurements commenced as detailed in Sections 3.2.2.2 & 3.2.7 for the emplaced calibration items and the GPO respectively. Additionally, the sensor system response to the item of interest, the 4.2-in mortar, was determined for each sensor platform using a 4-ft deep pit that was dug near the calibration lane by Parsons for the study. These measurements are detailed in Section 3.2.6.

The Site Safety Officer conducted a ‘tail-gate’ safety meeting each day that personnel were on site. The topic(s) for each day’s meeting was at the discretion of the Site Safety Officer. Roll was taken in the form of sign-in sheets which are kept on file at Blossom Point after the completion of the demonstration

Preventative maintenance inspections were conducted at least once a day by all team members, focusing particularly on the tow vehicle and sensor trailer. Any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios are available in the system spares inventory which was located on site.

3.2.2 System Performance / Calibration

3.2.2.1 Standard MTADS Sensor Calibration

For the GEMTADS array, the standard performance checks include three types of measurements. At the beginning of field work and again each morning quiet, static data are collected for a period (15 - 20 minutes or as directed by the QAO) with all systems powered up and warmed up (typically 30 minutes after the transmitter is turned on). Next, two calibration items, a 4" diameter Aluminum (Al) sphere and a ferrite rod bundle, are placed a standard distance above the center of each sensor coil several times in sequence to verify the response of each sensor to each object. The system is stationary for this data collection. Finally, a systems timing check using a fixed-position wire or chain placed on the ground is conducted. At the discretion of the QAO, the timing check may be repeated in the middle of the survey day. At the discretion of the QAO, the timing check and the Al sphere and ferrite measurements may be repeated at the end of the survey day.

For the EM61 MkII array, the standard performance checks are the same as for the GEMTADS with the ferrite rod measurements deleted. The ferrite rod is not a useful calibration item for this time-domain instrument. For the magnetometer array, the Al sphere measurements are also deleted and the quiet period is reduced to 5-10 minutes. Each sensor platform's performance check requirements are based on data rates and the historical stability and reproducibility of each sensor type.

3.2.2.2 Emplaced Sensor Calibration Items

A quiet area near the base camp was identified from the results of the initial magnetometer demonstration. Five calibration items were emplaced in a lane to verify proper system operation on a daily basis. The lane was left in place for the other data collection demonstrators and was removed after all data collection was complete by Parsons. The calibration items were surveyed each morning and each evening that data are collected. Data are digitally recorded, checked for appropriate signal strength and noise levels immediately, and inverted in post processing to verify consistency of parameter estimation. The calibration items were separated by a minimum distance of 5 m and were strategically placed to avoid anomalies detected in the same area during the initial magnetometer demonstration. The location of each calibration item was surveyed in using the man-portable RTK GPS system. The final schedule of the calibration items is given in Table 3-6.

Table 3-6 – Final Former Camp Beale Site 18 Calibration Item Schedule

Item	Easting (m)	Northing (m)	HAE (m)	Depth (cm)	Grid Orientation (deg)	Length (m)
4" Al Sphere	578,849.204	3,752,001.662	125.651	6	N/A	N/A
Shotput #1	578,846.064	3,751,994.346	125.594	10	N/A	N/A
Shotput #2	578,843.346	3,751,989.040	125.558	20	N/A	N/A
4.2" Mortar #1	578,839.851	3,751,981.456	125.413	35	293	0.469
4.2" Mortar #2	578,836.607	3,751,975.109	125.245	57	302	0.394

3.2.3 Period of Operation

The final schedule for the major items in the Demonstration is given in tabular form in Table 3-7. The schedule was adjusted on-site to accommodate site access restrictions, the vagaries of the weather, and other unavoidable conditions.

Table 3-7 – Camp Sibert Discrimination Study Demonstration Final Schedule

Date	Planned Action
Mon, April 2nd	Personnel arrive in Gadsden, AL. Establish base camp. Prepare magnetometer system for survey.
Tue, April 3rd	Emplace calibration lane. Conduct magnetometer pit measurements. Survey GPO with magnetometer. Start main magnetometer survey.
Wed, April 4th	Complete magnetometer survey.
Thu, April 5th	Assemble MTADS EM61 MkII system. Conduct EM61 MkII pit measurements. Survey GPO with EM61 MkII. Start main EM61 MkII survey.
Thu, April 12th	Complete EM61 MkII survey.
Fri, April 13th	Assemble GEMTADS system. Conduct GEMTADS pit measurements. Survey GPO with GEMTADS.
Sat, April 14th	Start main GEMTADS survey.
Tue, April 17th	Complete GEMTADS survey.
Wed, April 18th	Pack 53’ trailer.
Thu. April 19st	Trailer departs for Blossom Point, MD. Personnel depart site.
Mon, April 23rd	Trailer arrives at Blossom Point, MD.
Wed, April 25th	Data archives and anomaly analyses delivered to ESTCP.
Week of May 21st	Submit Draft Demonstration Data Report to ESTCP.

3.2.4 Scope of Demonstration

Data collection was conducted at the former Camp Sibert Site 18 ESTCP UXO Discrimination Demonstration Site, approximately 8 miles southwest of the City of Gadsden, AL at the request of the ESTCP Program Office. Three total coverage (100% coverage) surveys of the final demonstration site (15 acres) and the GPO were conducted. These surveys were conducted using the NRL MTADS magnetometer, EM61 MkII, and GEM-3 (GEMTADS) arrays. These data were collected in accordance with the requirements of the overall study demonstration plan including the use of emplaced calibration items and the GPO. Located, demedianed data from each sensor platform are provided as deliverables. Anomaly detection thresholds for the 4.2-in mortar were determined on-site using measurements of an example mortar in a prepared pit. All detected anomalies above the established, sensor array-specific thresholds for each sensor platform were reported. Based on the demonstration design, it was anticipated that there would be approximately 2000 anomalies for analysis from each system. For the GEMTADS and magnetometer arrays there were significantly more anomalies detected. A subset selection of those anomalies was made in cooperation with the Program Office and the selected anomalies were analyzed using the physics-based models of the MTADS DAS and UX-Analyze. The anomaly fit results (easting, northing, depth, size, etc.) were provided to the Program Office along with the data archives according the schedule in Table 3-7. A draft demonstration data report was submitted after the completion of the demonstration.

3.2.5 Operational Parameters for the Technology

The main operational parameters in this study are the anomaly detection thresholds for each sensor array and the determination of those thresholds. See Section 3.2.6 for the discussion of the determination of the detection thresholds. The GPO was used to validate the selected detection thresholds for Site 18 and the items of interest, the 4.2-in mortar. The results of the data collection in the GPO area are discussed in Section 3.2.7.

3.2.6 Anomaly Detection and Detection Threshold Selection

Individual anomalies for analysis were extracted from the individual data sets in a manner similar to that used for the initial magnetometer demonstration. Any anomaly with a peak magnitude of greater than a determined threshold was selected, the data surrounding the anomaly center extracted and submitted to the physics-based models resident in the MTADS DAS for the GEMTADS data, UX-Analyze for the EM61 MkII data, and a mixture of both for the magnetometer data as was most efficient. The modeling routines then return the fit results (northing, easting, depth, size, etc.) for each anomaly. The process of selecting an appropriate threshold requires information about the item of interest, the response of the sensor used to the item of interest, and the goals of the demonstration especially in terms of the depth of interest. Based on archival information, the item of interest for Site 18 of the Camp Sibert FUDS is the 4.2-in mortar (~107mm in diameter). The detection thresholds were selected based on the predicted peak anomaly magnitude for the item of interest. As the item of interest could be positioned in a range of orientations and at a range of depths, response curves can be generated bounding the sensor response at the most favorable orientation and at the least favorable orientation of the sensor / item of interest pair with respect to the exciting field and as a function of depth.

An example is given in Figure 3-2 for a Cs-vapor magnetometer system and a 105mm projectile. The upper curve represents the sensor response (in nT) for the most favorable orientation of the projectile with respect to the exciting field (the Earth's magnetic field) as a function of depth below the surface. The sensors travel an additional 25 cm above the surface. The lower curve represents the response for the least favorable orientation. Representative values of actual field measurements are shown as black circles. Two representative noise levels from recent deployments are also shown. The ESTCP UXO demonstration design sets the initial depth of interest to be 11x the diameter of the item of interest, or 1.17m for the 4.2-in mortar. At this depth, the anomaly detection threshold was set to be one-half the least-favorable predicted response by the Program Office and the Advisory Group. In this example where the least favorable response is predicted to be 16 nT, the anomaly detection threshold would be therefore 8 nT. As measurements on the 4.2-in mortar were not available for the initial magnetometer demonstration and given the fact that the 105mm projectile is a very similar diameter, the initial demonstration detection threshold was set to that determined in this example for the 105mm projectile.

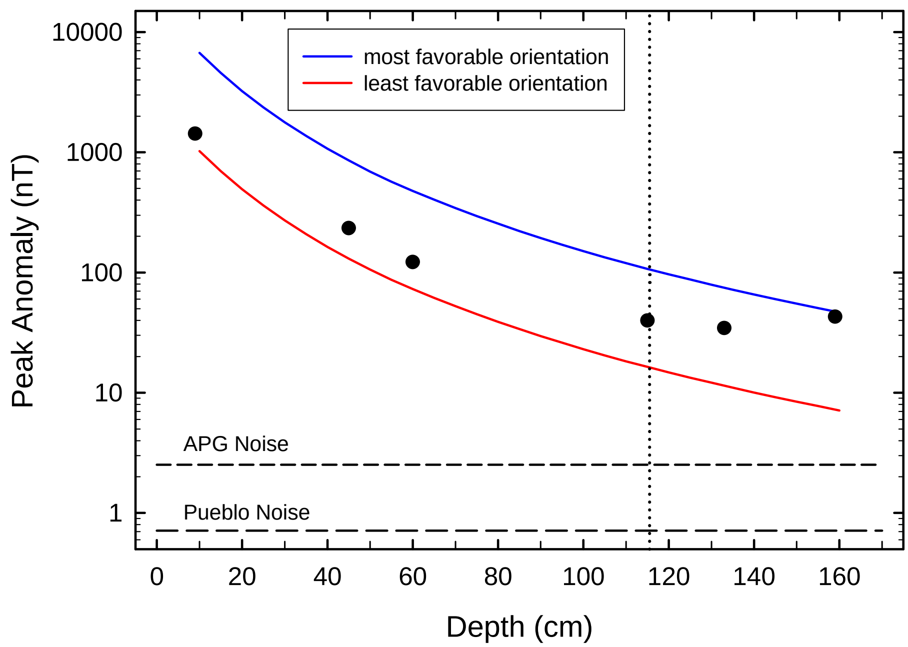

Figure 3-2 – Predicted magnetometer peak anomaly response versus depth for most and least favorable orientations for a 105mm projectile.

This approach was used to establish the system response as a function of depth and to determine the appropriate detection thresholds for all three sensor arrays using field measurements made at Site 18 and the 4.2-in mortar. A 4-foot deep pit was dug by Parsons for collecting these data. Using non-metallic spacers and shims, an example 4.2-in mortar provided by the USACE was placed at a series of depths and orientations or ‘scenes.’ Four examples are shown in Figure 3-3. Data were then collected using each sensor array in turn over the series of ‘scenes.’

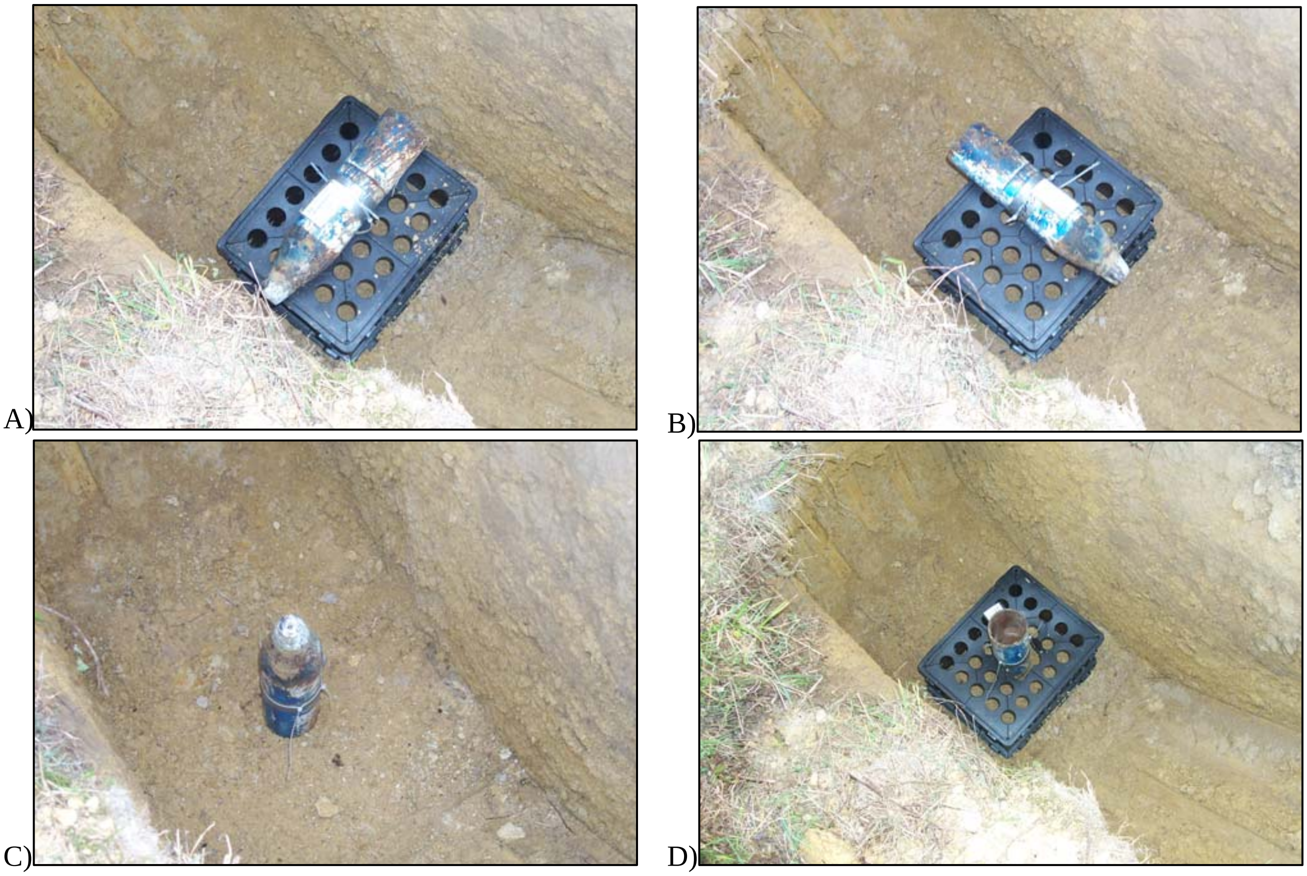

Figure 3-3 – Example ‘scenes’ from pit measurements at Site 18 of the 4.2-in mortar. A) Horizontal facing west, B) Horizontal facing north, C) Vertical nose up D) Vertical nose down

For the magnetometer system, the detection threshold was established using anomaly peak positive values extracted from the demedianed magnetometer data. The peak amplitude for the 4.2-in mortar was extracted from the data from each ‘scene’ and the results are shown in Figure 3-4. The segment of data surrounding the mortar for each ‘scene’ was then extracted and fit to the dipole model imbedded in the MTADS DAS. An ensemble average of the results from all scenes was then determined and used to generate the system response curves shown in Figure 3-4. After the demonstration was completed, the peak magnitudes for the seeded mortars in the GPO were also extracted. A summary of all of the results is shown in Figure 3-5. The least favorable response for the magnetometer system at a depth of 11x was found to be 12 nT. Including the factor of two safety margin, the anomaly detection threshold is 6 nT. These results are summarized in Table 3-8. The system RMS background level as determined from the GPO area is also shown as a dashed line. The RMS background levels for each sensor system are given in Table 3-9.

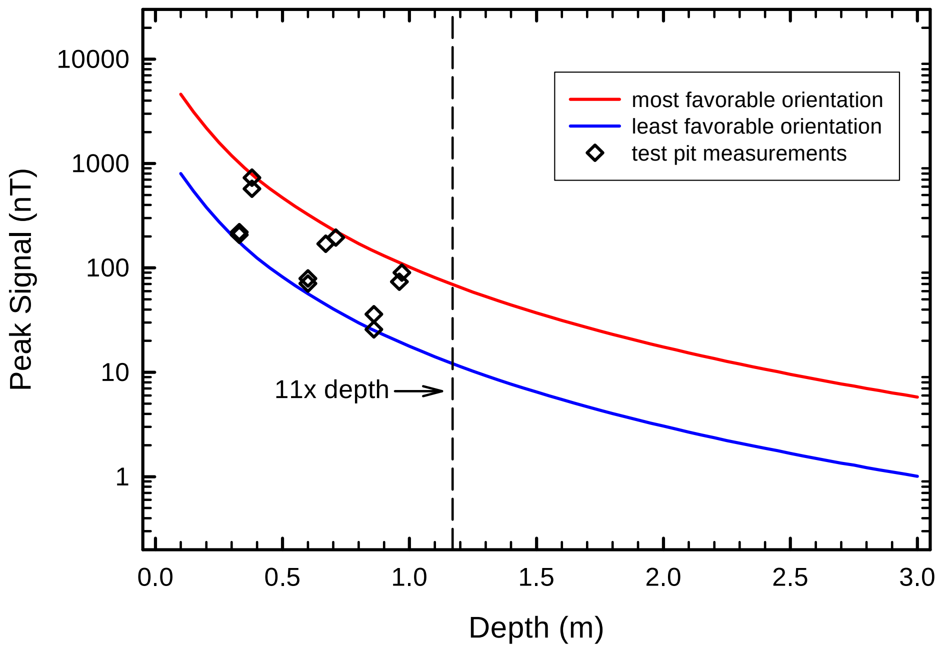

Figure 3-4 – Peak anomaly amplitude results from the MTADS magnetometer system and pit measurements of the 4.2-in mortar (open diamonds). The modeled system response for the most (red) and least (blue) favorable orientations of the mortar are shown as lines.

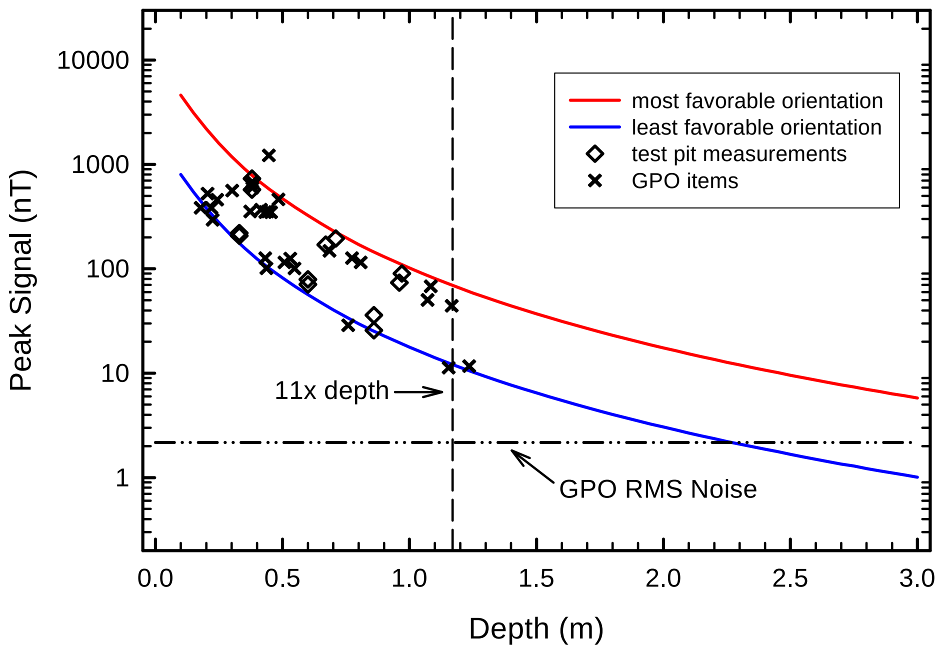

Figure 3-5 – Peak anomaly amplitude results from the MTADS magnetometer system and pit measurements of the 4.2-in mortar (open diamonds). The modeled system response for the most (red) and least (blue) favorable orientations of the mortar are shown as lines. The responses for the seeded GPO items are also shown as ‘x’s.

Table 3-8 – Minimum System Response and anomaly detection thresholds for the 4.2-in mortar

Array	Minimum Response at 11x	Anomaly Detection Threshold
Magnetometer	12 nT	6 nT
EM61 MkII	50 mV, S1	25 mV, S1
GEMTADS	2.6 ppm, Qave	1.3 ppm, Qave

Table 3-9 – Site 18 GPO RMS Background Level by Sensor Array

Array	RMS Background Level
Magnetometer	2.2 nT
EM61 MkII	6.4 mV, S1
GEMTADS	0.9 ppm, Qave

For the EM61 MkII, the detection threshold was based on the demedianed Gate 1 (bottom coil, 308 μs) data. The EM61 MkII array minimum system response (s1) for the 4.2-in mortar was 50 mV and the anomaly detection threshold was therefore 25 mV. The anomaly peak amplitude data and the calculated system response curves are shown in Figure 3-6 along with the post-demonstration analysis results from the seeded GPO items. For the GEMTADS array, the average mid-quadrature metric Q_{ave} was the basis data set for the anomaly detection threshold.

$$Q_{ave} = \frac{\sum(Q_{270Hz} + Q_{570Hz} + Q_{1230Hz} + Q_{2610Hz} + Q_{5430Hz})}{5}$$

The GEMTADS array minimum system response for the 4.2-in mortar was 2.6 ppm Q_{ave} and the anomaly detection threshold was therefore 1.3 ppm Q_{ave}. The anomaly peak amplitude data and the calculated system response curves are shown in Figure 3-7 along with the post-demonstration analysis results from the seeded GPO items. All detection thresholds were validated on the GPO in cooperation with IDA prior to use on data from the main survey areas.

A different approach to anomaly detection threshold selection without *a priori* knowledge of the item of interest has been used previously in this project [19,20,21] for Wide Area Assessment where the specific identity of the anomaly is less important. The determination of anomaly densities and the establishment of target area boundaries are a primary concern in WAA work. The results for a series of possible cut-off thresholds are examined and the threshold is determined based on the location of a change in curvature, or 'knee,' in the detected anomaly response. Such an analysis for the EM61 MkII array and the SouthEast 1 Area at Site 18 is shown in Figure 3-8. Vertical lines annotate several possible cut-off thresholds of interest. The results show a well defined 'knee' area and the selected anomaly detection threshold for this demonstration is within the conservative bounds determined during the WAA Pilot Project. A similar analysis for the SouthWest Area is shown in Figure 3-9. The SouthWest Area data does not exhibit a clear 'knee' and it would be more difficult to wisely select a detection threshold using this method. This is presumably due to the increased background in the SouthWest Area due to geology.

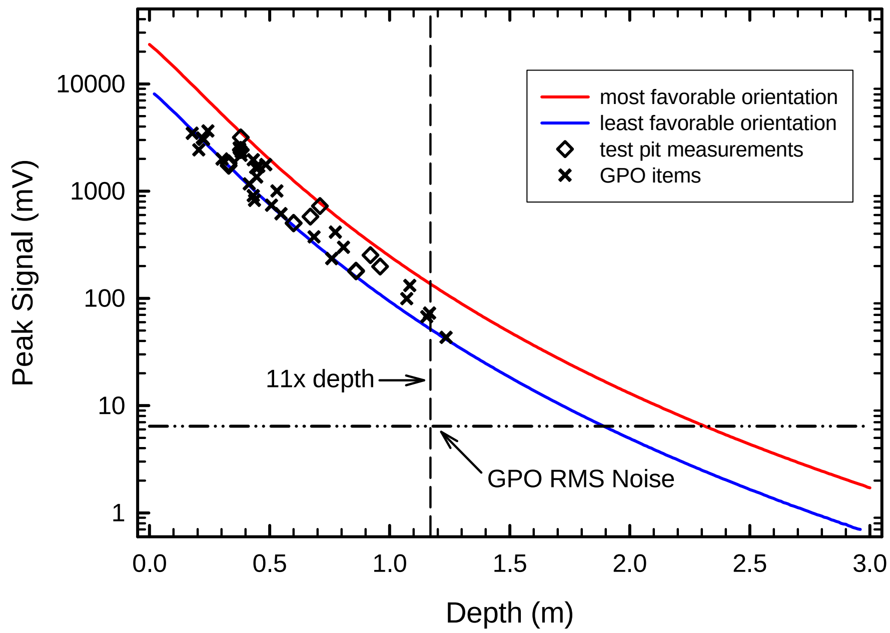

Figure 3-6 – Peak anomaly amplitude results from the MTADS EM61 MkII array system and pit measurements of the 4.2-in mortar (open diamonds). The modeled system response for the most (red) and least (blue) favorable orientations of the mortar are shown as lines. The responses for the seeded GPO items are also shown as ‘x’s.

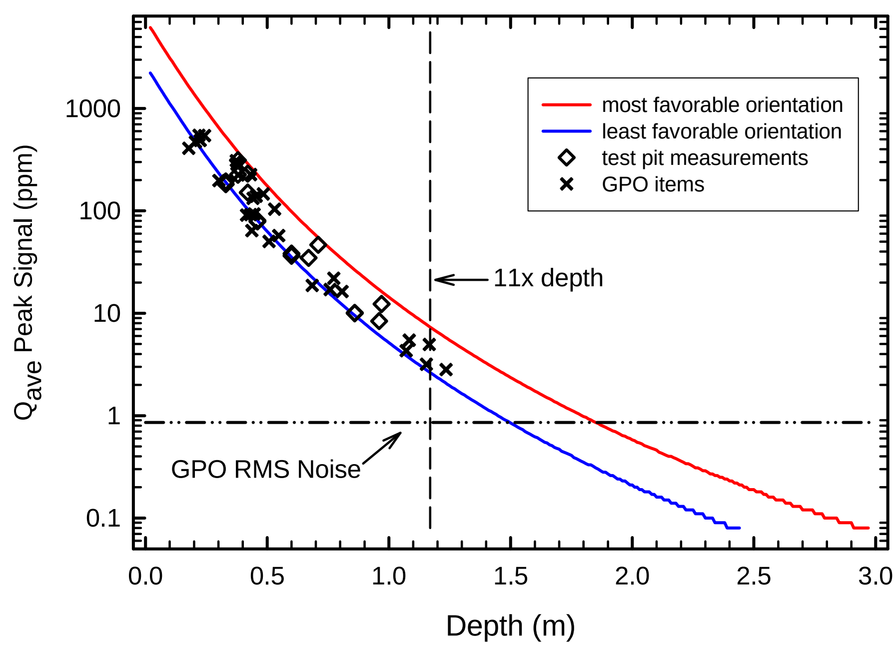

Figure 3-7 – Peak anomaly amplitude results from the MTADS GEM-3 array (GEMTADS) system and pit measurements of the 4.2-in mortar (open diamonds). The modeled system response for the most (red) and least (blue) favorable orientations of the mortar are shown as lines. The responses for the seeded GPO items are also shown as ‘x’s.

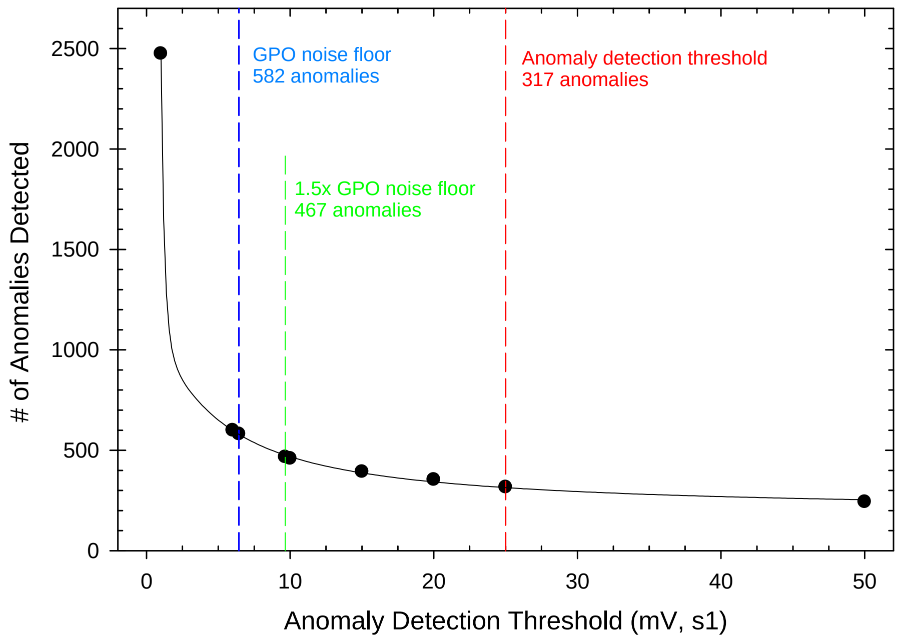

Figure 3-8 – Anomaly detection results for the EM61 MkII as a function of anomaly detection threshold for the SouthEast 1 Area at Site 18.

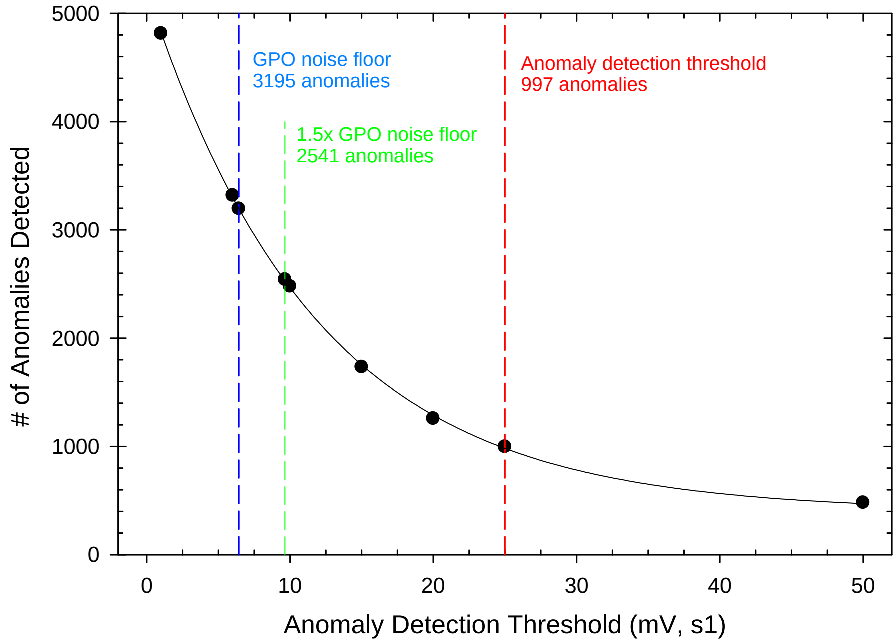

Figure 3-9 – Anomaly detection results for the EM61 MkII as a function of anomaly detection threshold for the SouthWest Area at Site 18.

3.2.7 Geophysical Prove Out (GPO)

A Geophysical Prove Out (GPO) area was established near the main demonstration area prior to the main demonstration data collection. The GPO was used to verify the anomaly detection thresholds for the three MTADS sensor systems to be demonstrated in the Study. The other data collection demonstrators also validated their systems and methods using the GPO. For this demonstration, the GPO was surveyed with each sensor platform (magnetometer, EM61 MkII, GEMTADS) prior to data collection in the main demonstration area with that sensor array. The intent of data collection in the GPO with each system is to verify that the items of interest are detected at the depths of interest under site-specific conditions and to validate the selected detection threshold for each sensor array as outlined in Section 3.2.6. No attempt was made to detect lower signal anomalies than those determined to be of interest prior to the study.

The location of the GPO was based on the results of the initial magnetometer survey and was placed in a reasonably quiet area in the southwestern corner of the SouthWest Area. An area 50m x 50m was selected for the GPO and a magnetic anomaly map of the initial magnetometer survey of the GPO is shown in Figure 3-10. The GPO area was cleared along with a 10m buffer on all sides by Parsons and the USACE prior to seed-item emplacement. The coordinates of the corners of the GPO are given in Table 3-10. The 4.2-in mortar was the primary item seeded into the GPO area. A number of 4.2-in half rounds (a round splayed out flat) were also emplaced. The number of seed items emplaced and the configuration of the GPO are not known to the demonstrators but are contained in the GPO Plan developed by IDA for the Program Office [22]. Prior to analysis of any data collected from the main demonstration area, the performance of each sensor platform on the GPO was evaluated in conjunction with the Program Office.

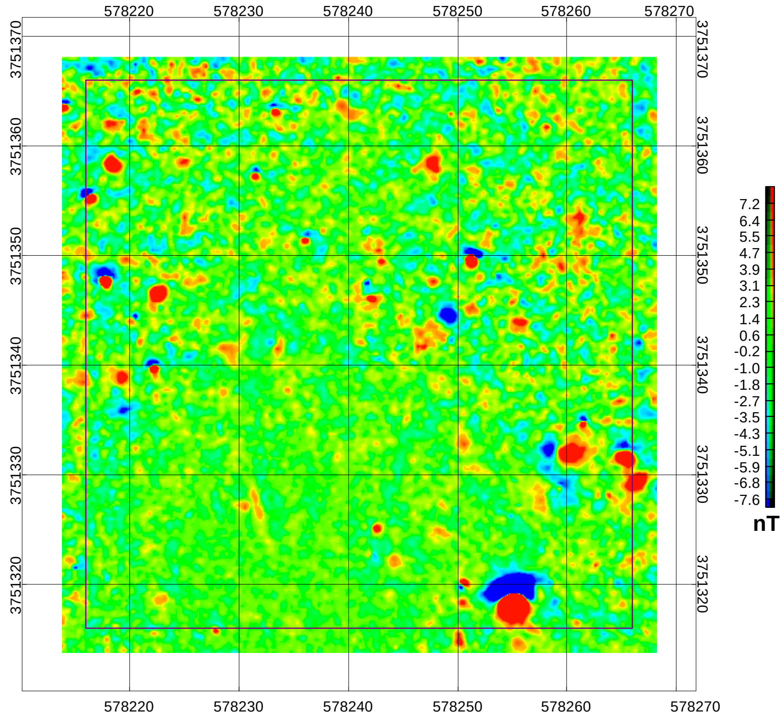

Figure 3-10 – Magnetometer anomaly map from the GPO prior to seed item emplacement. These data were collected during the initial magnetometer demonstration.

Table 3-10 – Coordinates of the Site 18 GPO Corners

Easting (UTM 16N, m)	Northing (UTM 16N, m)
578,266	3,751,366
578,266	3,751,316
578,216	3,751,316
578,216	3,751,366

A magnetic anomaly map of the magnetometer data set from the GPO collected during the main demonstration is shown in Figure 3-11. The locations of the detected anomalies using the detection threshold of 6 nT are indicated with the 'x' symbol. The locations of the seeded items are indicated with open circles. The two seed targets on the eastern edge of the northern boundary are placed in an area of relatively high geology-derived signal and based on surveyor data, emplaced at a depth of 125 cm or deeper which corresponds to a depth of 12x the 4.2-in mortar diameter or deeper. These depths are outside the design scope of the Study. Using the 6nT anomaly detection threshold, all of the seeded items are detected. The detections of the two deep seeded items appear to be chance detections and not based on clear detection of the item's signature. Comparing Figure 3-10 and Figure 3-11, one can see that several strong amplitude anomalies identified in the initial survey were left in place during the clearance phase. The total number of anomalies detected from the magnetometer data is listed in Table 3-11.

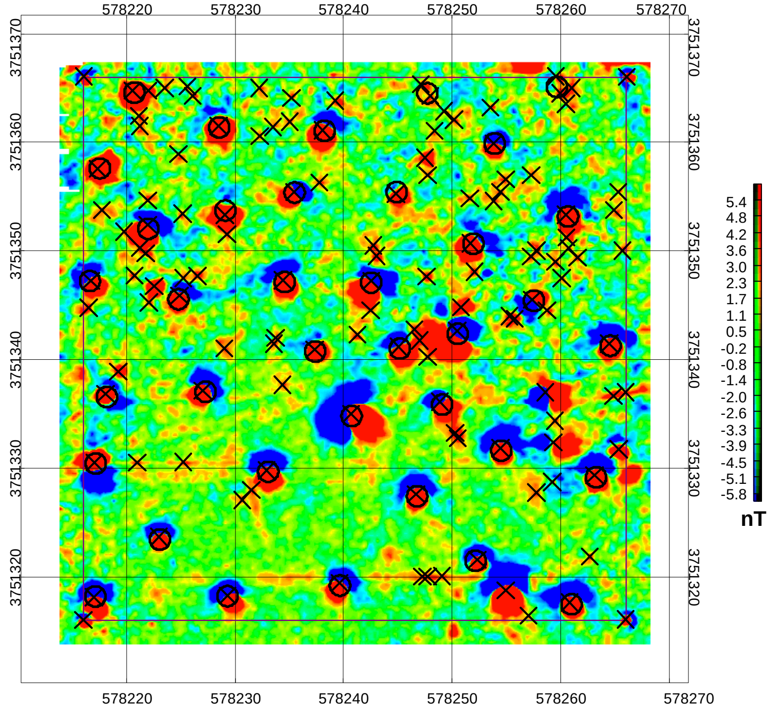

Figure 3-11 – Magnetometer anomaly map from the GPO from the main demonstration. These data were collected after the emplacement of the seed items. The 'x's mark the positions of the selected anomalies. The open circles mark the locations of the emplaced items.

Table 3-11 – Number of anomalies detected in the Site GPO using the site-specific anomaly detection thresholds

Sensor System	Number of detected Anomalies
Magnetometer	131
EM61 MkII	43
GEMTADS	97

The anomaly map for the first time gate (s1) of the MTADS EM61 MkII array is shown in Figure 3-12. All of the seeded items were detected along with a small number of additional anomalies. The total number of anomalies detected from the EM61 MkII data is listed in Table 3-11.

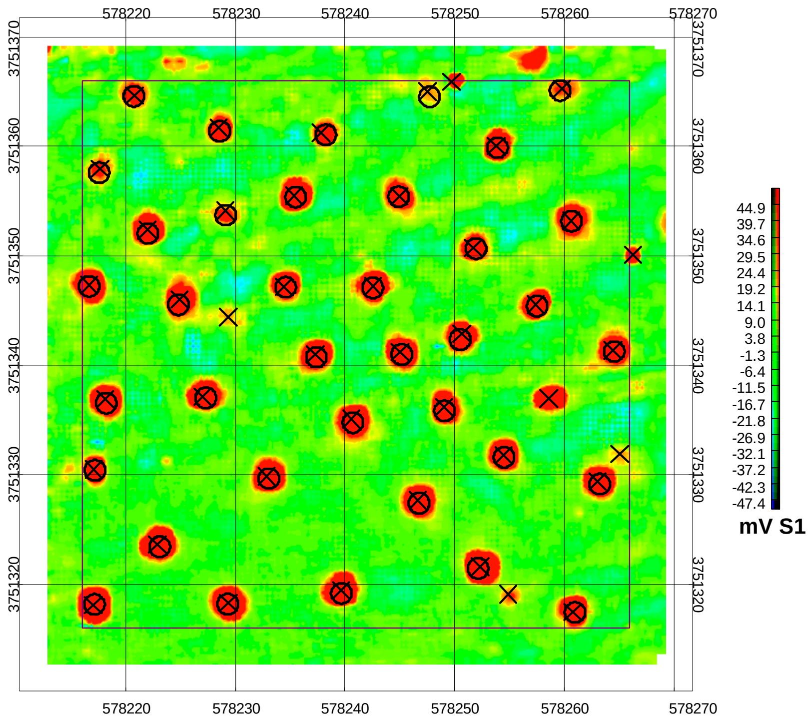

Figure 3-12 – EM61 MkII anomaly map from the GPO from the main demonstration. These data were collected after the emplacement of the seed items. The 'x's mark the positions of the selected anomalies. The open circles mark the locations of the emplaced items.

The anomaly map for the average mid-quadrature response (Q_{ave}) of the MTADS GEM-3 (GEMTADS) array is shown in Figure 3-13. All but one of the seeded items were detected along with an additional number of anomalies. The detections of two of the smaller amplitude anomalies are likely chance detections and not based on clear detection of the item's signature. The total number of anomalies detected from the GEMTADS data is listed in Table 3-11. Based on the system response results presented in the previous section and the GPO results presented in this section, the EM61 MkII array exhibits a higher signal-to-noise ratio than either the magnetometer or GEM-3 sensors in the presence of the local geology and background levels at this site. The magnetometer and GEM-3 sensors exhibit similar behavior in the Site 18 GPO area in terms of signal-to-noise ratio as a function of depth and number of additional anomaly detections at a threshold which captures the majority of the seed items. These results translate into a more definitive detection of the emplaced items of interest with fewer additional detected anomalies for Site 18 based on the GPO for the EM61 MkII array. Additionally, the majority of the EM61 MkII detected anomalies that do not correspond to emplaced seed items correspond to items that were previously identified and not removed during the clearance of the GPO and therefore are likely detection of a real anomaly.

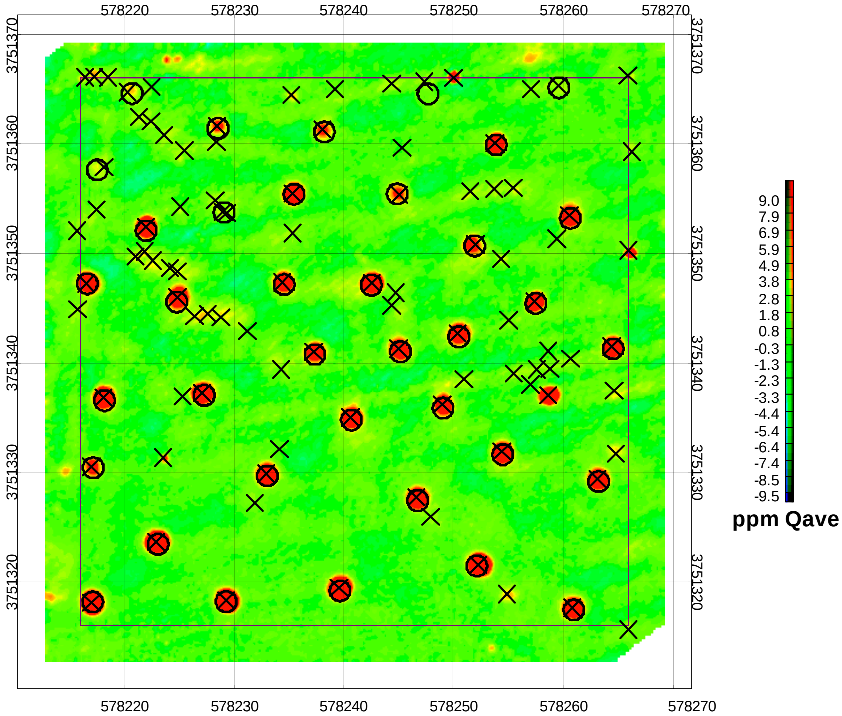

Figure 3-13 – GEMTADS anomaly map from the GPO from the main demonstration. These data were collected after the emplacement of the seed items. The 'x's mark the positions of the selected anomalies. The open circles mark the locations of the emplaced items.

3.2.8 Main Survey Area Results

The main demonstration area was divided into four areas as shown in Figure 3-1. The GPO was placed in a flat, geologically quiet (relatively) area in the southwest corner of the SouthWest Area from the initial magnetometer demonstration. A 9-acre portion of the original SouthWest area adjacent to the GPO was selected as a main demonstration area and retained the name SouthWest Area. Two portions of the SouthEast Area from the initial magnetometer demonstration were also selected for the main demonstration. A 5-acre section near the pond was selected and named the SouthEast 1 Area. A 1-acre section directly south of SouthEast 1 was also selected and named the SouthEast 2 Area. The survey results from each section of the main demonstration will be discussed in the following sections. The GPO results have been discussed in Section 3.2.7.

3.2.8.1 SouthWest Area

Anomaly maps for the demedianed magnetometer, the EM61 MkII s1, and the GEMTADS Q_{ave} responses for the SouthWest Area are given in Figure 3-14, Figure 3-15, and Figure 3-16, respectively. The corresponding GPO anomaly maps are also shown for reference. The number of anomalies extracted from each data set are summarized in Table 3-12. There were 901 anomalies extracted from the EM16 MkII s1 data set. As indicated in Table 3-12, a significantly larger number were extracted from the magnetometer and GEMTADS data sets. After discussion with the Program Office, all EM61 MkII anomalies were analyzed. The locations of the EM61 MkII anomalies were used as seed center locations for extracting corresponding anomalies from the magnetometer data. All GEMTADS anomalies were analyzed. Since a goal of this demonstration was to allow the Program Office to generate a master anomaly, or pick list, this concentration of effort was reasonable. As an additional exercise, the EM61 MkII anomalies were used as seed center locations for extracting corresponding anomalies from the GEMTADS data. While discussions were ongoing on how to best select the subset of anomalies to analyze, some of the larger amplitude anomalies extracted from the magnetometer data were analyzed without insuring correspondence to EM61 MkII anomalies. These results are included separately on the attached CD. All data archives, anomaly location results, and anomaly fit results are included on the attached CD.

Table 3-12 – Number of anomalies detected in the SouthWest Area using the site-specific anomaly detection thresholds

Sensor System	Number of detected Anomalies
Magnetometer	6241
EM61 MkII	901
GEMTADS	2644

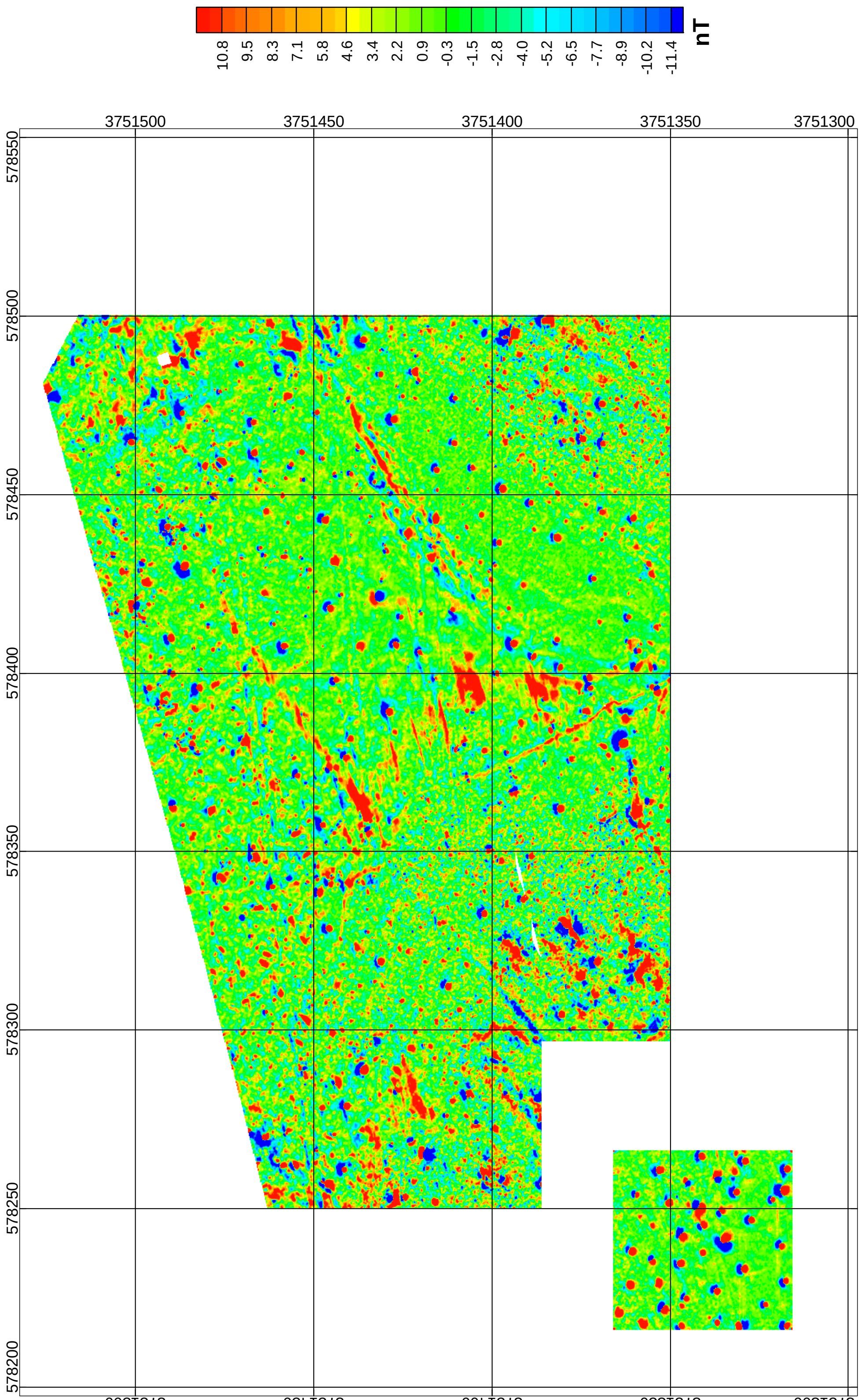

Figure 3-14 – Magnetometer anomaly map from the SouthWest Area of the main demonstration site.

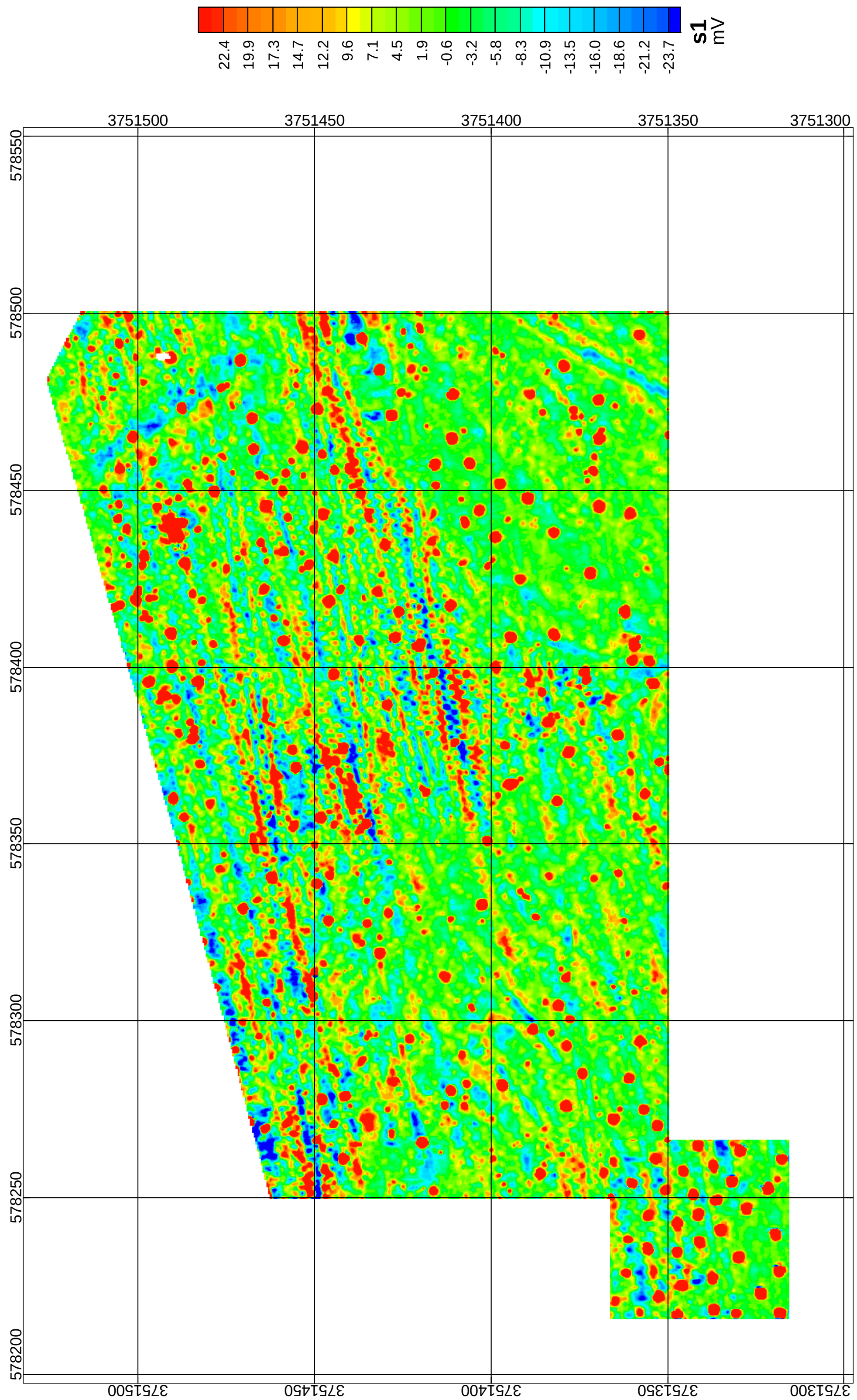

Figure 3-15 – EM61 MkII s1 anomaly map from the SouthWest Area of the main demonstration site.

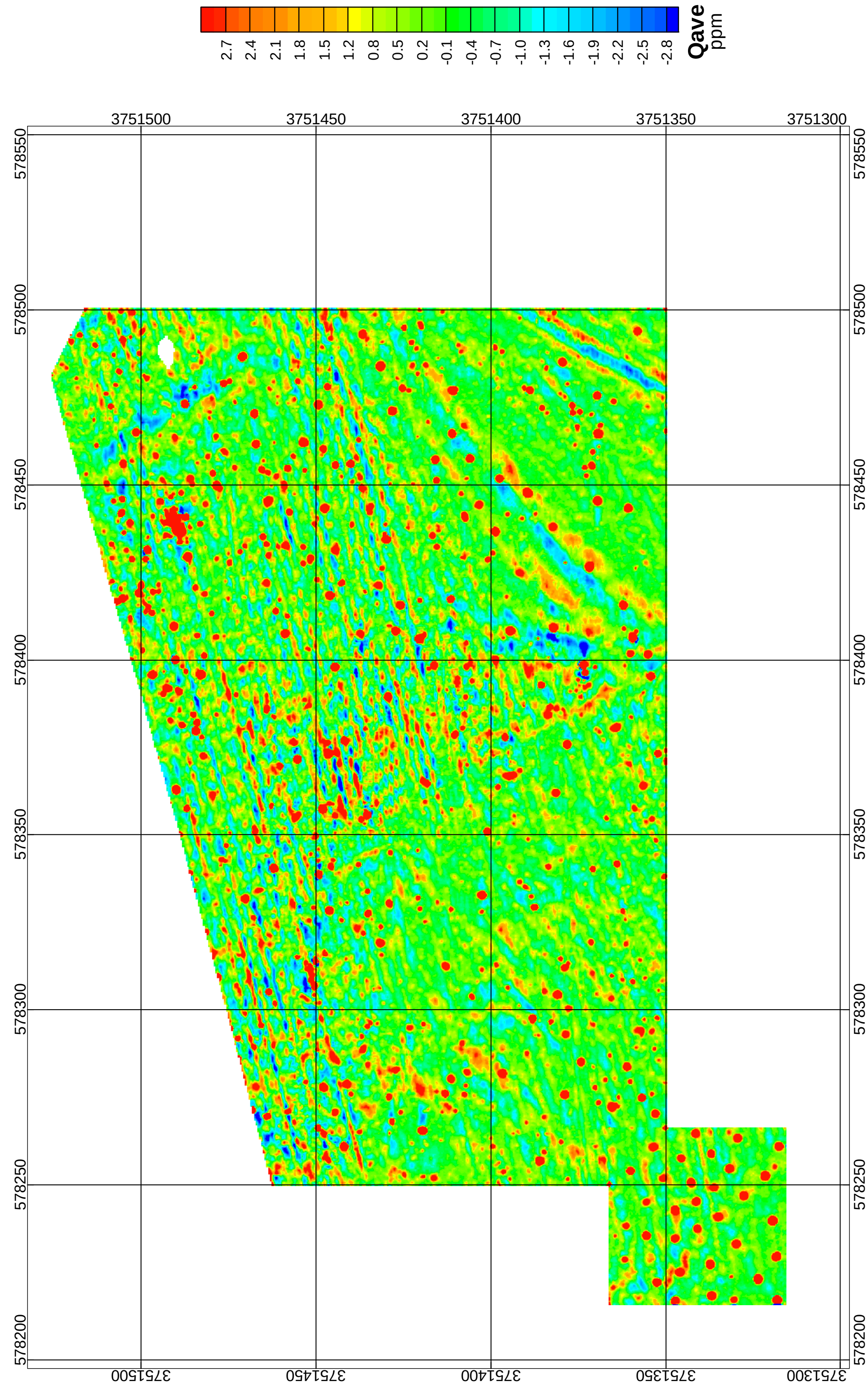

Figure 3-16 – GEMTADS Q_{ave} anomaly map from the SouthWest Area of the main demonstration site.

3.2.8.2 SouthEast 1 Area

Anomaly maps for the demedianed magnetometer, the EM61 MkII s1, and the GEMTADS Q_{ave} responses for the SouthEast 1 Area are given in Figure 3-17, Figure 3-18, and Figure 3-19, respectively. The number of anomalies extracted from each data set are summarized in Table 3-13. The geology evident in the anomaly maps from the SouthWest Area was greatly reduced in the SouthEast Areas, resulting in only a few hundred anomaly detections per sensor per area. Therefore all anomalies extracted from all three data sets were individually analyzed. All data archives, anomaly location results, and anomaly fit results are included on the attached CD.

Table 3-13 – Number of anomalies detected in the SouthEast 1 Area using the site-specific anomaly detection thresholds

Sensor System	Number of detected Anomalies
Magnetometer	588
EM61 MkII	282
GEMTADS	596

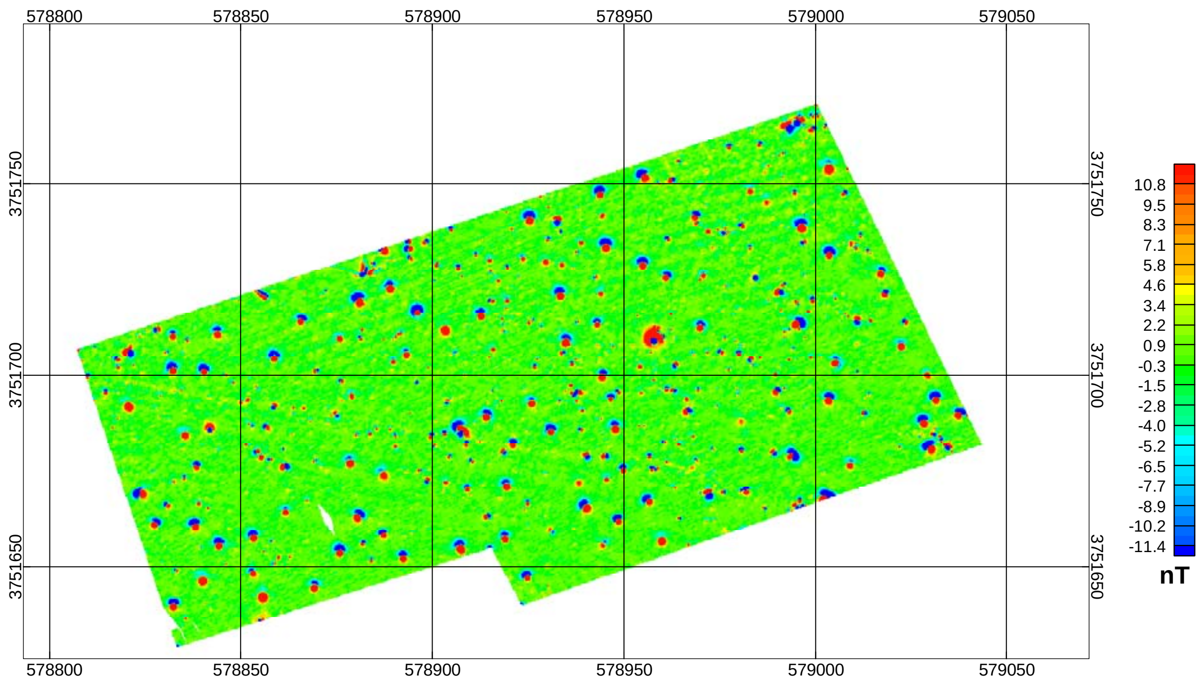

Figure 3-17 – Magnetometer anomaly map from the SouthEast 1 Area of the main demonstration site.

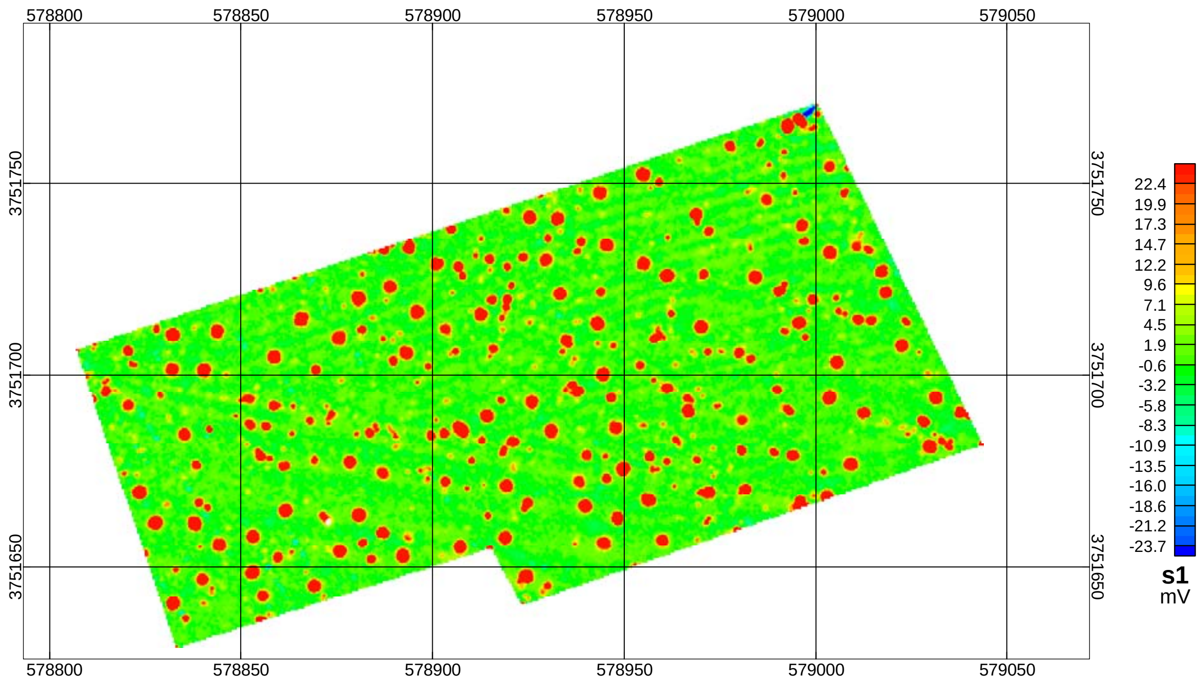

Figure 3-18 – EM61 MkII s1 anomaly map from the SouthEast 1 Area of the main demonstration site.

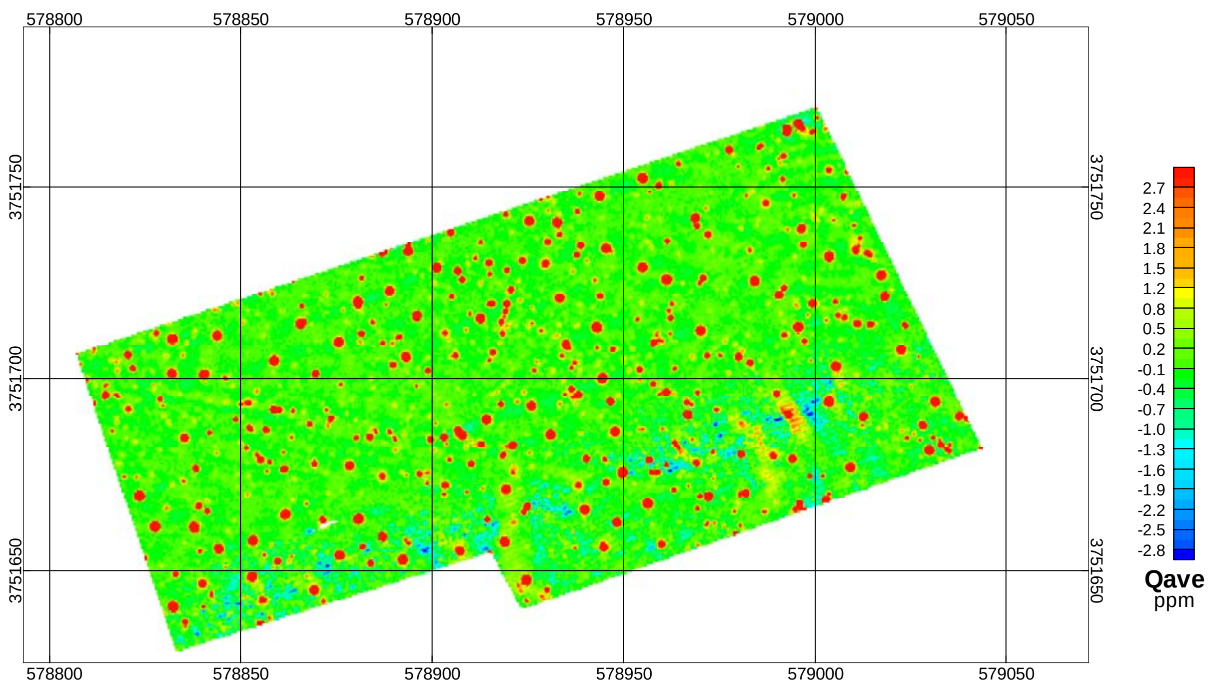

Figure 3-19 – GEMTADS Q_{ave} anomaly map from the SouthEast 1 Area of the main demonstration site.

3.2.8.3 SouthEast 2 Area

Anomaly maps for the demedianed magnetometer, the EM61 MkII s1, and the GEMTADS Q_{ave} responses for the SouthEast 2 Area are given in Figure 3-20, Figure 3-21, Figure 3-22, respectively. The number of anomalies extracted from each data set are summarized in Table 3-14. The geology evident in the anomaly maps from the SouthWest Area was greatly reduced in the SouthEast Areas, resulting in only a few hundred anomaly detections per sensor per area. Therefore all anomalies extracted from all three data sets were individually analyzed. All data archives, anomaly location results, and anomaly fit results are included on the attached CD.

Table 3-14 – Number of anomalies detected in the SouthEast 2 Area using the site-specific anomaly detection thresholds

Sensor System	Number of detected Anomalies
Magnetometer	485
EM61 MkII	121
GEMTADS	245

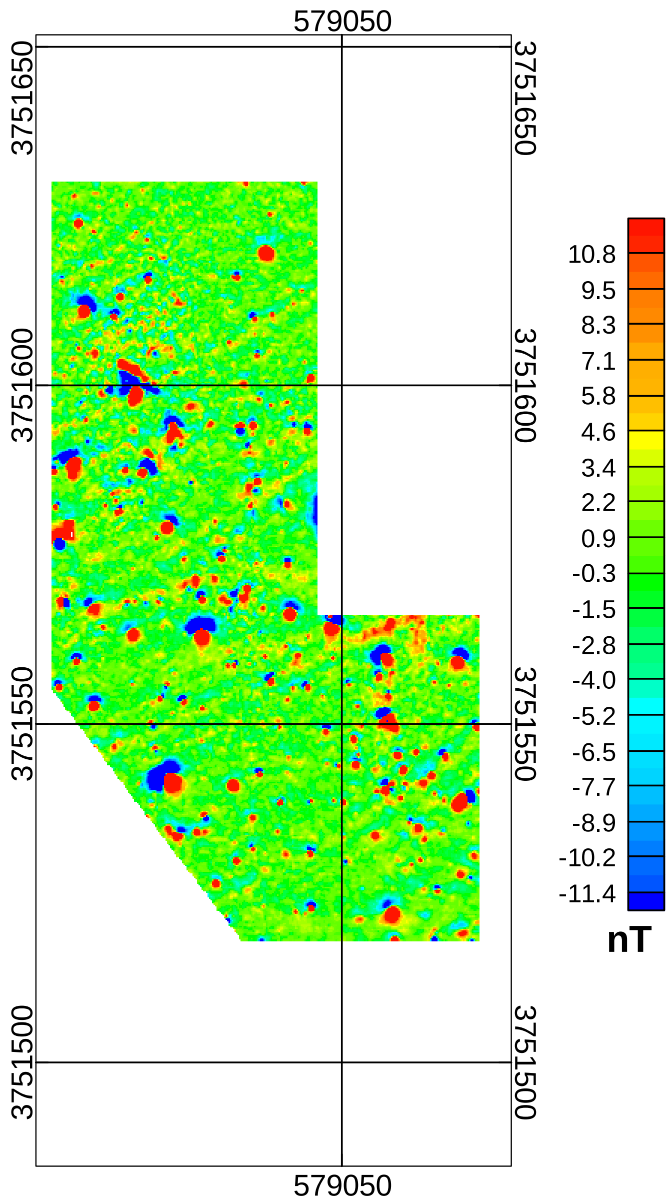

Figure 3-20 – Magnetometer anomaly map from the SouthEast 2 Area of the main demonstration site.

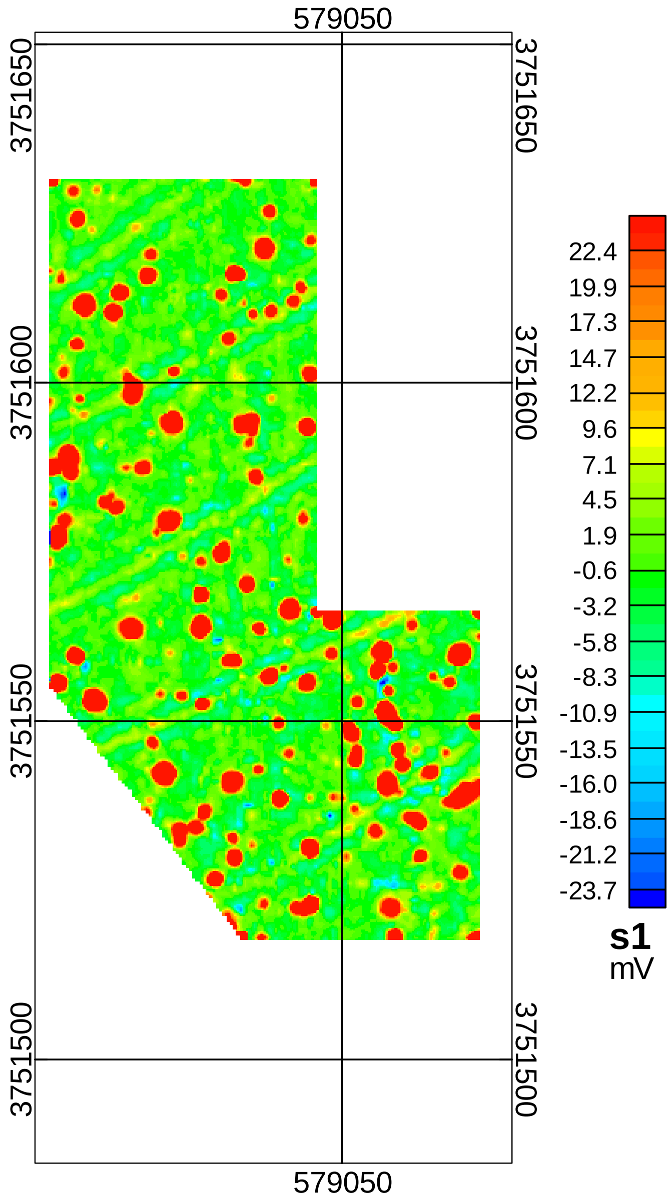

Figure 3-21 – EM61 MkII s1 anomaly map from the SouthEast 2 Area of the main demonstration site.

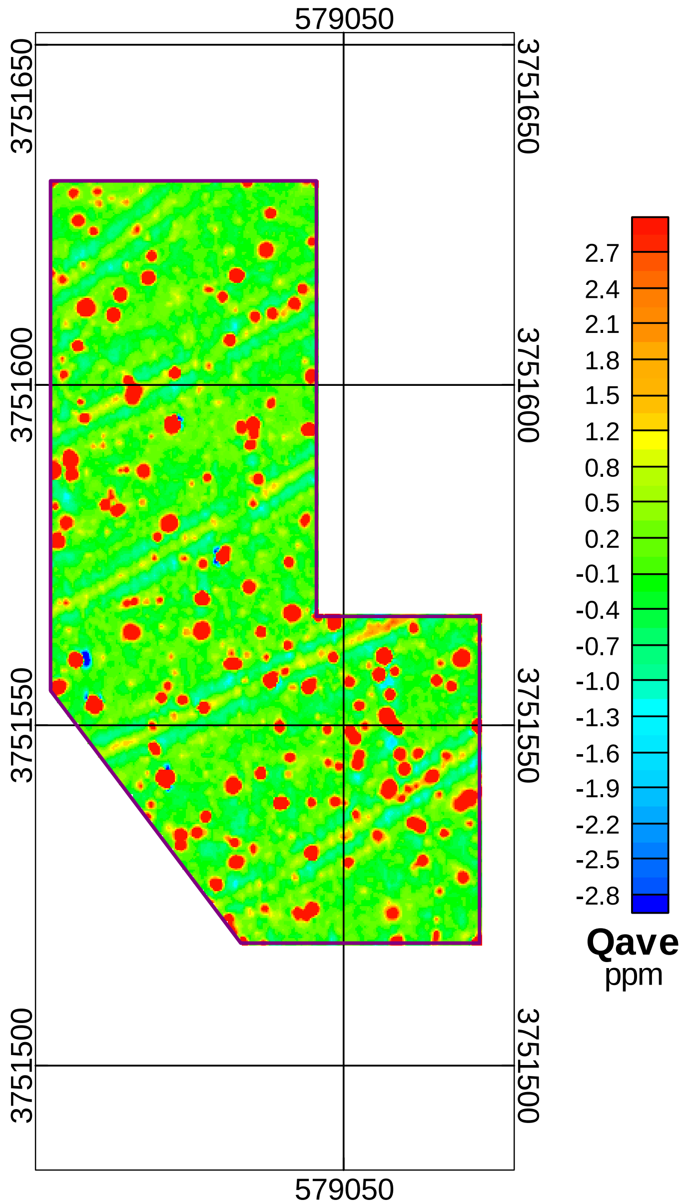

Figure 3-22 – GEMTADS Q_{ave} anomaly map from the SouthEast 2 Area of the main demonstration site.

3.2.9 Systems Performance and Calibration Item Results

As mentioned in Section 3.2.2, a calibration lane was emplaced in the East Area from the initial magnetometer demonstration. Table 3-6 gives the schedule of the emplaced items and parameters (i.e. depth and orientation). Figure 3-23 shows an EM61 MkII array (s1) anomaly map of the Site 18 calibration lane. The midpoint positions of the emplaced items, as determined by RTK GPS waypointing, are shown as open circles.

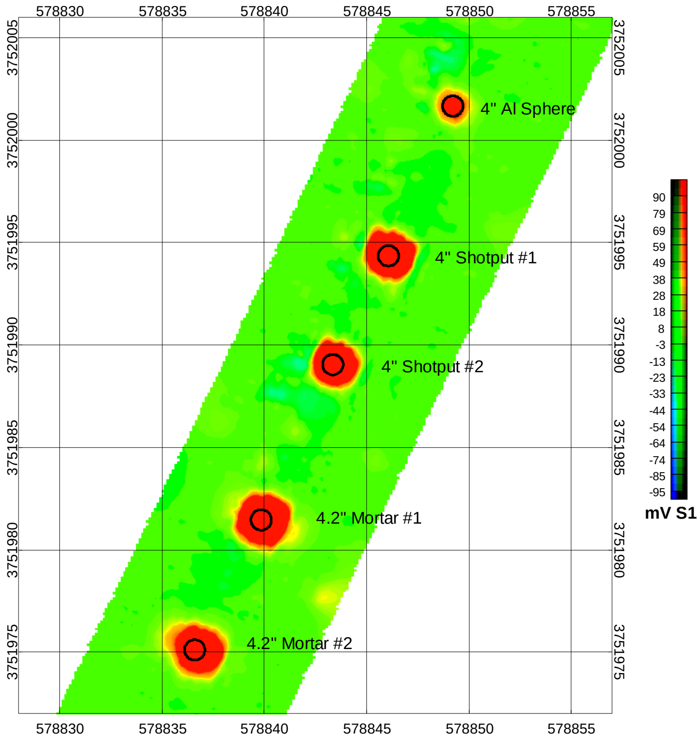

Figure 3-23 – EM61 MkII array s1 anomaly map of the Site 18 calibration lane emplaced in the East Area. The midpoint positions of the emplaced items are shown as open circles

Each field day involving data collection commenced with a warm up period for the sensors, 10 – 30 minutes depending on the specific sensor in use. The RTK GPS network was established during the warm up period as well. After the warm up period, 5 – 20 minutes of data with the platform stationary and the vehicle engine turned off were collected. After the static survey, the calibration lane was surveyed. To insure that complete signatures for each emplaced item were recorded, a calibration lane survey was comprised of 3-5 passes, depending on the sensor platform. At the end of each field day involving data collection, the calibration lane was surveyed again prior to system shutdown in the same manner. To evaluate the data from the calibration items, the peak anomaly amplitude for each emplaced item in each survey was determined. For the magnetometer data, the peak positive amplitude was determined. The peak amplitude was extracting using a small snippet of data around the item's location. A finer grid (0.05m versus the 0.25m used for anomaly detection) was used. Since the data snippet was small, approximately 10 meters on a side, the finer mesh could be used without suffering a processing time penalty. An 11m x 8m sub-area immediately south of the calibration lane, identified to be relatively free of anomalies, was used for each data set to extract a small segment of the data set. The coordinates of the sub-area corners are listed in Table 3-15. The standard deviation (1σ) was then calculated for the sub-area and that value was reported as the driving background value for each calibration survey. The aggregate peak amplitude values for each survey of the calibration lane (average and standard deviation (1σ)) are tabulated in Table 3-16, Table 3-17, Table 3-18, for the magnetometer, the EM61 MkII, and the GEMTADS arrays respectively.

Table 3-15 – Corner coordinates of the area for calculating the driving background sensor levels

Easting (UTM 16N, m)	Northing (UTM 16N, m)
578,827.844	3,751,964.242
578,827.844	3,751,971.897
578,839.223	3,751,964.242
578,839.223	3,751,971.897

Table 3-16 – Peak Positive Aggregate Demedianed Magnetometer Values for Calibration Lane Emplaced Items

Item	Easting (m)	Northing (m)	HAE (m)	Depth (cm)	Grid Orientation (deg)	Length (m)	Avg. Signal (nT)	Std. Dev (nT, 1σ)
Driving Background (1s)	578,833.534	3,751,968.070	N/A	N/A	N/A	N/A	1.4	0.1
4" Al Sphere	578,849.204	3,752,001.662	125.651	6	N/A	N/A	N/A	N/A
Shotput #1	578,846.064	3,751,994.346	125.594	10	N/A	N/A	283.0	23.8
Shotput #2	578,843.346	3,751,989.040	125.558	20	N/A	N/A	182.2	20.9
4.2" Mortar #1	578,839.851	3,751,981.456	125.413	35	293	0.469	162.8	3.3
4.2" Mortar #2	578,836.607	3,751,975.109	125.245	57	302	0.394	69.5	4.1

Table 3-17 – Peak Aggregate Demedianed EM61 MkII Values for Calibration Lane Emplaced Items

Item	Easting (m)	Northing (m)	HAE (m)	Depth (cm)	Grid Orientation (deg)	Length (m)	Avg. Signal (s1, mV)	Std. Dev. (s1, mV, 1σ)
Driving Background (1s)	578,833.534	3,751,968.070	N/A	N/A	N/A	N/A	1.6	0.1
4" Al Sphere	578,849.204	3,752,001.662	125.651	6	N/A	N/A	169.9	6.2
Shotput #1	578,846.064	3,751,994.346	125.594	10	N/A	N/A	1265.5	52.8
Shotput #2	578,843.346	3,751,989.040	125.558	20	N/A	N/A	963.0	43.0
4.2" Mortar #1	578,839.851	3,751,981.456	125.413	35	293	0.469	1478.1	55.3
4.2" Mortar #2	578,836.607	3,751,975.109	125.245	57	302	0.394	549.9	27.9

Table 3-18 – Peak Aggregate Demedianed GEMTADS Values for Calibration Lane Emplaced Items

Item	Easting (m)	Northing (m)	HAE (m)	Depth (cm)	Grid Orientation (deg)	Length (m)	Avg. Signal (Qave, ppm)	Std. Dev (Qave, ppm, 1σ)
Driving Background (1s)	578,833.534	3,751,968.070	N/A	N/A	N/A	N/A	0.35	0.06
4" Al Sphere	578,849.204	3,752,001.662	125.651	6	N/A	N/A	27.79	7.06
Shotput #1	578,846.064	3,751,994.346	125.594	10	N/A	N/A	327.14	32.00
Shotput #2	578,843.346	3,751,989.040	125.558	20	N/A	N/A	155.10	14.96
4.2" Mortar #1	578,839.851	3,751,981.456	125.413	35	293	0.469	173.33	7.87
4.2" Mortar #2	578,836.607	3,751,975.109	125.245	57	302	0.394	43.73	0.99

Figure 3-24 and Figure 3-25 plot the peak anomaly amplitude values for the 4.2-in Mortar #1 and the 4-in Aluminum Sphere for all data sets in a time series as examples. For the EM61 MkII array, the 4.2-in Mortar #1 had the largest peak amplitude values. The 4-in Aluminum Sphere values were approximately 1/10 those for the 4.2-in Mortar #1 and are approximately seven times the final anomaly detection threshold chosen for the MkII array. The solid line indicates the aggregate average and the dashed lines indicate a 1σ envelope.

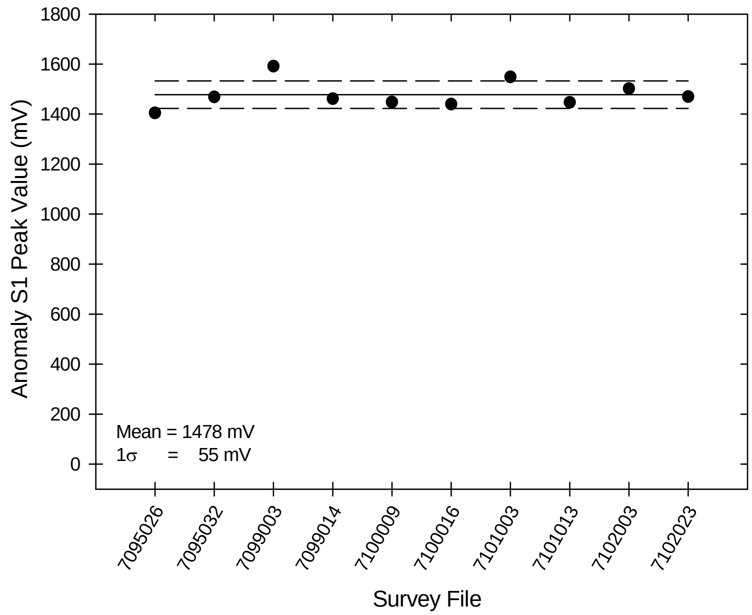

Figure 3-24 – Peak anomaly amplitude values from each EM61 MkII array calibration lane survey for the 4.2-in Mortar #1. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average peak positive value and the dashed lines represent a 1σ envelope.

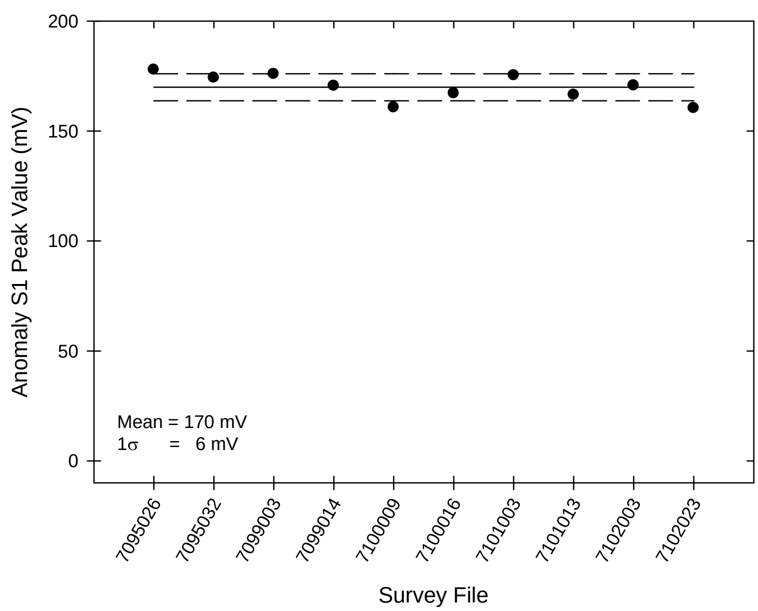

Figure 3-25 – Peak anomaly amplitude values from each EM61 MkII array calibration lane survey for the 4-in Aluminum Sphere. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average peak positive value and the dashed lines represent a 1σ envelope.

Stationary system performance tests of the sensor platform were conducted at the beginning of each survey day. After the system warm up period (approximately 10 – 30 minutes), walk-around preventative maintenance inspections, and the establishment of RTK GPS, the tow vehicle was driven to the southern edge of the calibration lane. A data set was collected for 5 – 20 minutes, depending on sensor platform, while the vehicle was kept stationary and engine turned off. Every effort was made to minimize the movement of personnel and equipment in the vicinity of the MTADS during this data collection. The 2-D positioning variation was evaluated by computing the standard deviation of both the northing and easting components of the position data for the entire period and combining them as the square root of the sum of the squares. The standard deviation for the demedianed sensor data from each sensor was computed and the arithmetic mean was computed for each data set. In occasional cases, an obvious artifact was present in the data (e.g. a vehicle pulls up along side the tow vehicle unannounced) and distorts a portion of the static run. In these cases, only the unperturbed data were used. The aggregate average and standard deviation (1σ) of both the positioning and sensor data for all data sets were computed. The results are shown in the following time-series figures. Figure 3-26 shows the 2-D position variation for the entire demonstration and the summary results are tabulated in Table 3-19. The stationary tests from April 15, 2007 were conducted using a new tarp to protect the GEM-3 electronics from moisture and the weather. The new tarp was initially installed over all three GPS antennae. During the stationary testing, it was determined that the tarp was causing unacceptable performance from the GPS receivers. The tarp was repositioned to avoid covering the GPS antennae prior to any dynamic data collection that day.

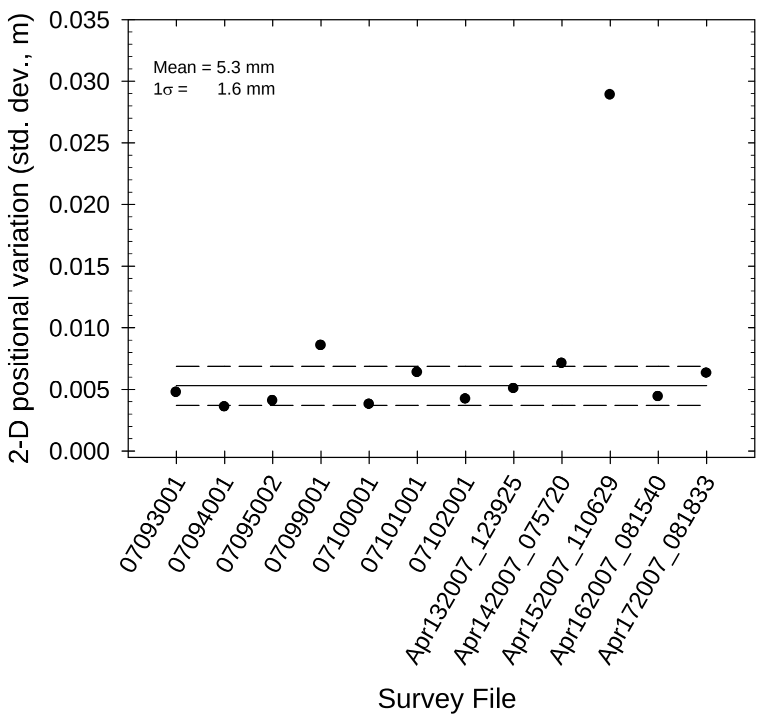

Figure 3-26 – 2-D position variation data runs for stationary data collected at the south end of the Site 18 calibration lane. The horizontal axis is survey file name. The solid line represents the aggregate average positional variation and the dashed lines represent a 1σ envelope.

The mean and standard deviation for the data set without the April 15 data are also plotted on Figure 3-26 as a solid line and a pair of dashed lines, respectively. Table 3-19 includes entries for both the entire data set and without the April 15 data.

Table 3-19 – Stationary Position Variation Results

Result Type	Value
2-D Position (all)	0.73 ± 0.70 cm
3-D Position (all)	1.22 ± 0.63 nT
2-D Position (- Apr15)	0.53 ± 0.16 cm
3-D Position (- Apr15)	1.05 ± 0.20 nT

Figure 3-27, Figure 3-28, and Figure 3-29 show the sensor variations from the stationary data collections broken out by sensor platform; magnetometer, EM61 MkII, and GEMTADS respectively. Table 3-20, Table 3-21, and Table 3-22 summarizes the stationary EM sensor data collection results. It should be noted that each sensor platform was only deployed for a few days, so the variations reported do not have a large enough sample size to be statistically relevant. However, the reported values are instructive, taken in that context.

The magnetometer system was only fielded for two days. The static sensor levels were within the bounds of past experience. The EM61 MkII static sensor levels increased slightly during the last two days of use. For example, as shown in Figure 3-28, the Gate 1 static sensor value increased 0.3 mV on Julian date 07101 and remained high for 07102. It is not clear at this time what caused this increase but the batteries which power the EM systems in the MTADS system were found to be one year old and were replaced prior to the next deployment as a proactive measure. As seen in Figure 3-29, on April 16, 2007, the Q_{ave} static value increased by a factor of three. Investigation showed that sensor 1 had not completely warmed up prior to the stationary measurement, as seen in the calculated Q_{ave} value. On April 17, the last day of data collection, all three sensors had completely warmed up and the Q_{ave} value returned to within the 1σ envelope.

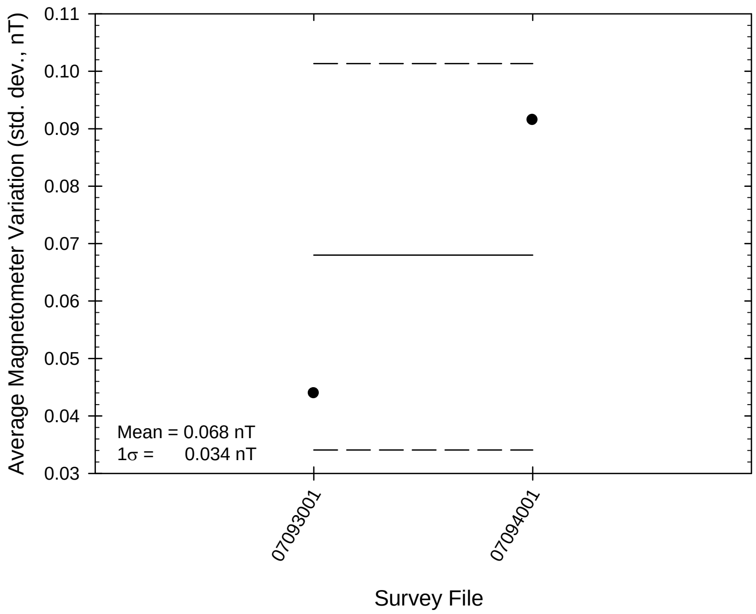

Figure 3-27 – Overall magnetometer (all sensors) variation data runs for static data collected at the calibration strip. The horizontal axis is survey file number. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope.

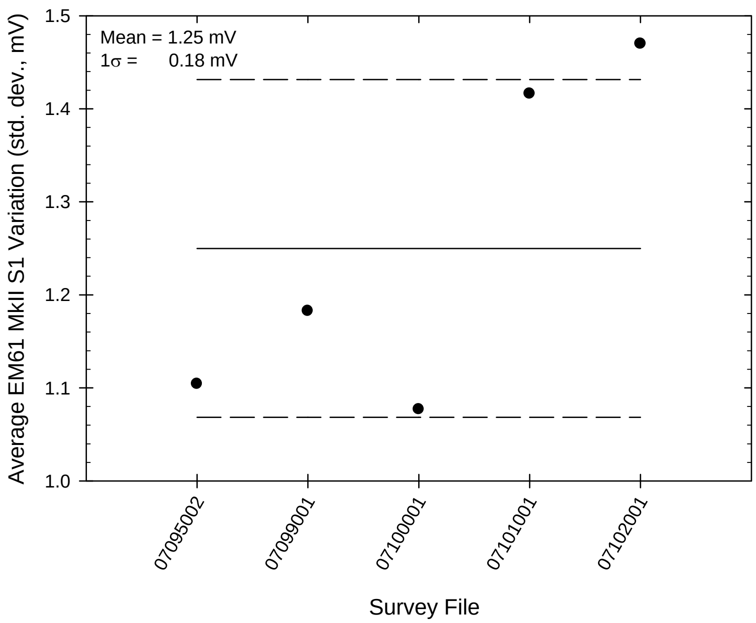

Figure 3-28 – Overall variation of MTADS EM61 MkII array, s1 time gate only for daily stationary data collection. The horizontal axis is survey file number. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope.

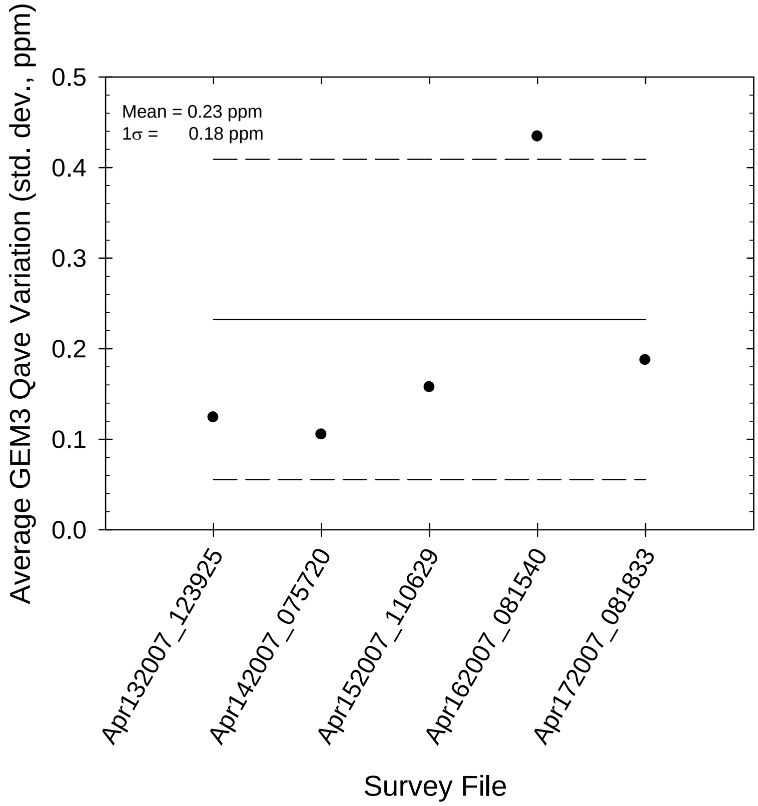

Figure 3-29 – Overall variation of GEMTADS, Q_{ave} value for daily stationary data collection. The horizontal axis is survey file name. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope.

Table 3-20 – Magnetometer Array Static Test Data Results (demedianed values)

Result Type	Value
Magnetometer	0.068 ± 0.034 nT

Table 3-21 – EM61 MkII Array Static Test Data Results (demedianed values)

Result Type	Value
Gate 1	1.25 ± 0.18 mV
Gate 2	1.02± 0.34 mV
Gate 3	1.04 ± 0.80 mV
Gate 4	0.64 ± 0.34 mV
Bottom Gates	0.98 ± 0.43 mV
All Gates	0.86 ± 0.20 mV

Table 3-22 – GEM-3 (GEMTADS) Array Static Test Data Results (demedianed values)

Result Type	Value
Q_{ave}	0.232 ± 0.177 ppm

3.2.10 Demobilization

At the end of field operations, all equipment, materials, and supplies were packed in the Navy-owned 53' trailer prior to personnel departing the site. Harris Transportation, a government-contracted transportation company picked up the trailer and returned it to Blossom Point. The connex was removed from the site once all Study-related efforts were completed.

3.2.11 Health and Safety Plan (HASP)

A host organization exists for this demonstration site. All field work was done under the authority of the existing work plan. An Abbreviated Accident Prevention Plan (AAPP) was prepared as part of the initial magnetometer demonstration to supplement the existing work plan in cooperation with the US Army Corps of Engineers, Huntsville. The completed and signed document is on file with the USACE, Huntsville office.

3.3 Management and Staffing

The responsibilities for this demonstration are outlined in Figure 3-30. Dr. Daniel Steinhurst was the PI of this project and filled the roles of Site / Project Supervisor and Quality Assurance Officer. Mr. Glenn Harbaugh was the Site Safety Officer and Data Acquisition Operator. His duties included data collection, safety oversight for the entire team, and managing the field technicians. Dr. Nagi Khadr was the Data Analyst for this effort. Ben Dameron of NAEVA Geophysics assisted with the data collection. First Choice Personnel of Gadsden, AL provided additional field personnel on an as-needed basis.

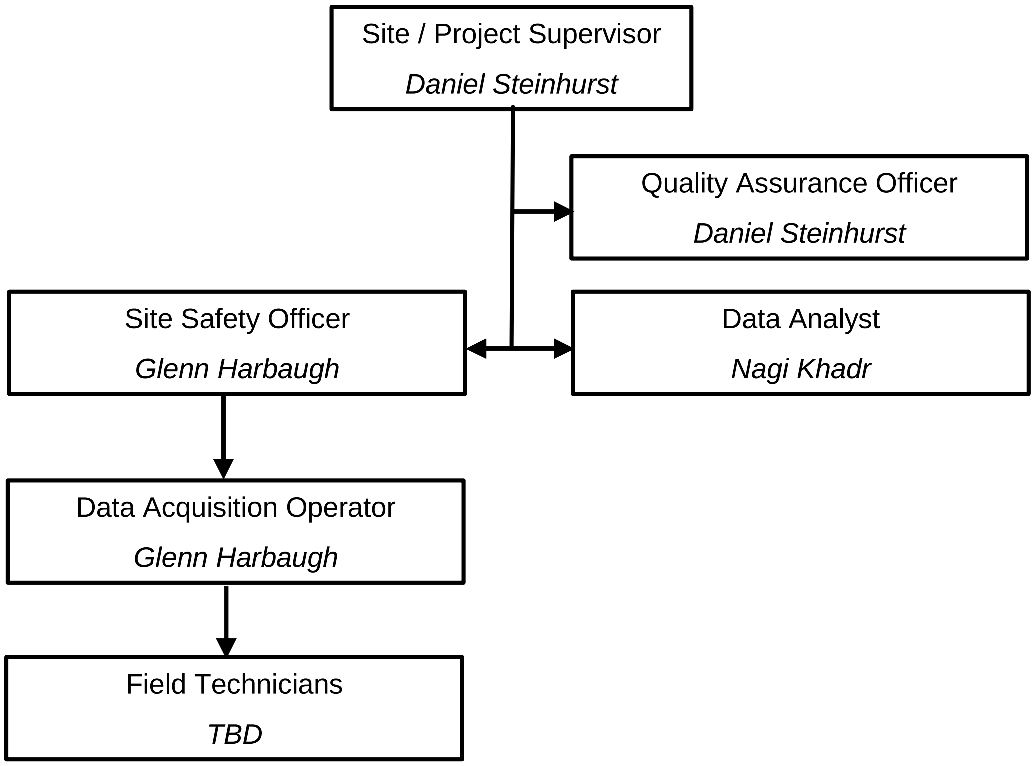

Figure 3-30 – Management and Staffing Wiring Diagram

4. Performance Assessment

4.1 Performance Objectives and Confirmation Methods

The Performance Criteria for the demonstration were introduced in combination with the Performance Objectives in Table 3-1 in Section 3.1 of this document. Table 3-1 is reproduced here as part of Table 4-1. The performance metrics "Signal to Noise Ratio (SNR) for Calibration Items" was deleted because the 4.2-in mortar is not an item emplaced at the Standardized Test Fields. Refer to Section 3.2.6 for a detailed discussion of the modeled versus actual measured signal amplitudes as a function of depth for the 4.2-in mortar.

Table 4-1 – Primary Transect Performance Objectives/Metrics and Confirmation Methods

Type of Performance Objective	Performance Criteria	Expected Performance (Metric)	Performance Confirmation Method	Actual Performance Objective Met?
Qualitative	*Reliability and Robustness*	*General Observations*	*Operator feedback and recording of system downtime (length and cause)*	*Yes*
Quantitative	*Survey Rate*	*Varies with sensor array, 5 (EM) – 20 (Mag) acres / day*	*Calculated from survey results*	*Yes*
	Data Density	*> 30 pts / m*^{2}	*Calculated from survey results*	*Yes*
	Percentage of Assigned Coverage Completed	*100% as allowed by topography / vegetation*	*Calculated from survey results*	*Yes*
	Location of Modeled Anomalies	*Horizontal: < ± 0.15 m Vertical: < 30% for depths ≥ 30 cm, < ± 0.15 m depths < 30 cm*	*Comparison of model results to known data on emplaced items or validation data on remediated items*	*Yes*
	Detection of GPO items of interest to depth of interest using determined thresholds	*100%*	*Comparison of anomaly lists from GPO to GPO ground truth for each sensor array*	*Yes*
	Data throughput	*All data QC'ed in real time and results (data and anomaly analysis) provided as required by Program Office*	*Analysis of records kept / log files generated while in the field and recorded delivery times*	*Yes*

Reliability and Robustness: The MTADS tow vehicle and magnetometer array are designed for off-road operations in rugged terrain with demonstrated operational success in a variety of desert [16,20] and plains / grasslands environments [3,19]. This demonstration involved the collection of high quality data with respect to the above data quality objectives at four closely spaced areas. Work was only halted due to limited site access (e.g. morning hunting expeditions), extreme weather situations (e.g. active local tornado watches), and to switch between the sensor arrays. The EM61 MkII survey was slowed by the intermittent and finally complete failure of one of the three GPS receivers in the vehicle. The time required to identify, diagnose, and repair the problem resulted in an increased rate of rejected survey data that had to be resurveyed, decreasing the survey rate (see below).

Survey Rate: The analysis of this performance metric is based on the recorded start and end times of the survey files associated with each survey area and sensor system. The combined area of the four survey areas (GPO, SouthWest, SouthEast 1, and SouthEast 2) is 15.6 acres, or 63,060 m^2. For the purposes of the analysis, the survey rate is calculated assuming a standard

MTADS survey day comprised of 8 useful hours of surveying, with 1 additional hour dedicated to the required sensor calibration and calibration lane data collections. The final hour of the typical ten-hour work day is devoted to daily setup and takedown. The results are shown in Table 4-2.

At first inspection, the resulting survey rates are lower than expected. However, there are several contributing factors to consider. First, the expected surveys rates listed in Table 3-1 and Table 4-1 are based on the aggregate performance of the MTADS systems on large (30-100 acres), open areas with long survey lines (400-600 m), open access on all sides of the areas for system turnarounds, and no site access restrictions. This was generally not the case at Site 18 and therefore the survey rate would be expected to be lower. The four survey areas ranged in size from 0.6 to 9 acres with a total acreage of only 15.6 acres. The SouthEast survey areas and the western edge of the SouthWest and GPO areas approach tall tree lines which required extra vigilance to maintain RTK solutions on all of the GPS receivers during turnarounds. These factors all resulted in reduced efficiency and therefore survey rate. An additional factor contributing to the survey rate for the magnetometer system was that the Parsons teams were still in the process of emplacing the seed items on site during the survey, resulting in periods where we could not collect data because the next survey area was not completely seeded yet. The small acreage of the demonstration areas allowed the demonstration schedule to continue as planned, even allowing for the above discussed issues and weather / site access issues, even finishing data collection a day earlier than planned. For these reasons and the overarching desire to collect the best possible quality data possible, we feel that the performance metric was met.

Table 4-2 – Survey Rates for Former Camp Sibert Site 18 by Sensor System

Sensor System	Survey Time (hours)	# of Field Days	# of Std. Survey Days	Survey Rate (acres / std. day)
Magnetometer	16.1	2	2.0	7.8
EM61 MkII	36.0	5	4.5	3.5
GEMTADS	30.2	5	3.8	4.1

Data Density: This performance metric is calculated from the number of good data points recorded within each survey area and the size of each survey area (in m^2). The resulting values are given in Table 4-3. The data density for the MTADS magnetometer system is approximately three times higher than the EM systems, as expected. The MTADS magnetometer system records data at 50 Hz (as compared to approximately 10 Hz for the EM systems) and drives at twice the speed of the EM systems. The magnetometer array has 8 sensors while the EM sensors have effectively 6 sensors once the orthogonal or interleaved survey patterns used are considered. Multiplying all of these factors together combines to a factor of 3.3. For the majority of the survey areas and sensor systems, the recorded data density is at or above the performance metric. For the EM systems in the SouthWest Area and the EM61 MkII array in the SouthEast 1 Area, the data densities dip below the 30 pts/m^2 mark but not by more than 17%.

Table 4-3 – Resultant Data Density by Survey Area and Sensor System

		Data Density (pts/m^2)		
Survey Area	**Area (m^2)**	**Magnetometer**	**EM61 MkII**	**GEMTADS**
SouthWest	36,200	98	27	25
SouthEast1	19,354	98	27	30
SouthEast2	5,002	114	37	31
GPO	2,500	102	31	34

Percentage of Assigned Coverage Completed: On large open ranges the vehicular MTADS proves to be an efficient survey technology. Surveys with the magnetometer array often exceed production rates of 20 acres per day. The presence of certain non-navigable terrain features such as thick stands of trees, ravines and gullies without good crossing points, and other non-navigable features can limit the areas that could be surveyed. With the exception of the footprint of a few trees located within the survey areas, 100% of the four survey areas were surveyed successfully with each of the three sensor systems. For this demonstration, the stands of trees tightly bordering the sites limited the available horizon for GPS satellites. At certain times of day the survey areas near the tree lines, especially on the western edges, could not be surveyed due to an insufficient number of properly oriented GPS satellites. Vigilant monitoring of the GPS system status allowed us to relocate the survey efforts to unaffected areas during these periods. Large amounts of rain rendered small portions of the site unsurveyable during the initial magnetometer survey. The amount of rainfall during this demonstration was significantly lower as can be seen by comparing the system coverage in the SouthEast 1 Area for the three sensor systems in Figure 3-17, Figure 3-18, and Figure 3-19 to the results of the original magnetometer demonstration [23].

Location of Modeled Anomalies: The individual anomaly analysis results for the Site 18 GPO from each sensor array were transmitted to the Program Office for validation prior to extracting anomalies and the corresponding anomaly analysis for the other survey areas. As part of the validation process, IDA determined which submitted anomaly corresponded with which emplaced item based on reported position. The results of this effort were transmitted back to us as one list for each sensor system with the Northing, Easting, and Depth offsets reported for each anomaly. These results form the basis for the analysis of this performance metric. Two types of 4.2-in mortars were emplaced in the GPO, intact recovered 4.2-in mortars and splayed, or half rounds, where the recovered mortar has split on one side and formed a basically flat sheet. The half rounds, which were emplaced at shallower depths, are called out separately.

For the magnetometer system, the statistics on miss distance, Easting offset, and Northing offset, and depth offset are given in Table 4-4. For the depth offset, the intact rounds are divided into items with emplacement depths of less than 30 cm (Shallow) and those which are deeper (Deep). The half round results are also given separately in Table 4-4 and all are treated as shallow emplaced items. The EM61 MkII array results are presented in Table 4-5 and the GEMTADS array results are given in Table 4-6. The modeled position results for the three sensor arrays were comparable with the exception of the accuracy of the depth predictions for the deep (> 30 cm) emplaced objects. For the deeply emplaced items, the performance corresponded to the relative strengths of the three sensor arrays. The magnetometer array has the best performance for deep items. The increased transmit power of the EM61 MkII array design gives it the second best performance for depths. One design goal of the MTADS EM61 MkII was to locate 60mm mortars at depth approaching 1m. The sequential transmitter scheme of the GEMTADS array does not provide the depth capability of the other two arrays, and consequential, the GEMTADS has the lowest performance in terms of modeled depths for the deeper emplaced items.

Table 4-4 – Magnetometer GPO Emplaced Item Offsets

	Miss Distance (m)	Easting Offset (m)	Northing Offset (m)	Depth Offset (m)	Shallow Depth Offset (m)	Deep Depth Offset (m)
Overall						
Average	0.113	-0.005	-0.082	0.080	0.116	14%
Std. Dev (1s)	0.129	0.069	0.134	0.255	0.106	
Half Rounds Only						
Average	0.068	0.001	-0.034		0.047	
Std. Dev (1s)	0.054	0.073	0.039		0.056	

Table 4-5 – EM61 MkII GPO Emplaced Item Offsets

	Miss Distance (m)	Easting Offset (m)	Northing Offset (m)	Depth Offset (m)	Shallow Depth Offset (m)	Deep Depth Offset (m)
Overall						
Average	0.119	-0.010	0.005	0.190	0.181	45%
Std. Dev (1s)	0.094	0.108	0.107	0.160	0.152	
Half Rounds Only						
Average	0.042	0.007	-0.003		0.106	
Std. Dev (1s)	0.027	0.035	0.038		0.058	

Table 4-6 – GEMTADS GPO Emplaced Item Offsets

	Miss Distance (m)	Easting Offset (m)	Northing Offset (m)	Depth Offset (m)	Shallow Depth Offset (m)	Deep Depth Offset (m)
Overall						
Average	0.158	-0.012	-0.027	0.267	0.158	90%
Std. Dev (1s)	0.152	0.183	0.120	0.379	0.203	
Half Rounds Only						
Average	0.040	0.020	0.001		0.087	
Std. Dev (1s)	0.045	0.044	0.038		0.116	

Detection of GPO items of interest to depth of interest using determined thresholds: See Section 3.2.7 for a detailed discussion of the performance of the three sensor systems with respect to detection depth and thresholds.

Data throughput: All field data were QC'ed and processed in near real time and on site to provide immediate feedback on data quality. All data products and interim reports were delivered to the ESTCP Program Office per the required schedule which is summarized in Table 3-7.

5. Cost Assessment

5.1 Cost Reporting

Cost categories for this demonstration are mobilization, field survey, data analysis, demobilization, and reporting. Table 5-1 details the costs of mobilization, demobilization, and reporting for the entire demonstration. The costs for data collection with each sensor system and the associated data analysis are presented separately.

5.2 Cost Analysis

5.2.1 Cost Comparison

Within the context of the ESTCP UXO Discrimination Study, a complete unit of UXO discrimination effort includes a geophysical sensor, data collection mode or system, and a data processing scheme to generate a prioritized dig list, as discussed in Section 1.2.2. To generate complete costs for comparison is therefore beyond the scope of this report and will be addressed in future overall Discrimination Study reports. The costs for the three demonstrated data collection efforts are provided here. The overall costs of the demonstration are provided in Table 5-1 broken out by category (e.g., mobilization).

5.2.2 Cost Basis

The anticipated cost bases for this technology demonstration are the number of acres / day which can be surveyed by each sensor system and the rate at which the data can be processed and anomalies can be extracted and individually analyzed. The acreage of the survey sites and the number of days required for the data collection are given in Section 4.1, Table 4-1 for each sensor system and partially carried forward to Table 5-2. The required effort (in person-days) for the data analysis process to generate anomaly reports with individual anomaly analyses are also given in Table 5-2. The cost of data collection and data analysis for each sensor system are then provided along with total data collection time and costs for each sensor system. The mobilization, demobilization, and reporting costs are fixed costs determined by the deployment and are not included in these costs.

5.2.3 Cost Drivers

Two factors were expected to be strong drivers of cost for these technologies as demonstrated. The first is the acreage which can be surveyed per day. The actual acreage covered sets the amount of data collected per day. Higher productivity in data collection equates to more total acreage covered for a given period of time in the field. The scheduled turn-around period for selecting and analyzing individual anomalies was very short for this demonstration and potentially could have become a cost driver due to the time involvement. The thoughtful use of available automation techniques for individual anomaly analysis with operator QC support provided the required data products within the required time table. Due to the relative maturity of the data analysis visualization tools, the GEMTADS analysis QC effort took longer than the magnetometer and EM61 MkII analysis. The time and costs in Table 5-2 reflect this fact.

Table 5-1 – Overall Demonstration Costs by Category

		Item Cost ($)	Sub-Total ($)
Mobilization			**17,250**
	53' Trailer Rental / Amortization	1,600	
	Trailer Tranporation	3,500	
	Base Camp Connex Delivery	864	
	Equipment Preparation and Packing	6,588	
	Data Processing Laptop	2,160	
	Facilities Delivery	108	
	Team Travel to Site	2,430	
Field Work			**94,708**
	53' Trailer Rental / Amortization	1,200	
	Base Camp Connex Rental	126	
	Facilities Rental	216	
	Materials & Consumables	3,240	
	Supervisor	13,948	
	Vehicular Operator	9,882	
	Field Technician	12,150	
	Local Temp Worker	1,620	
	System Maintenance	9,720	
	Per Diem for Team	10,206	
	SUV Rental Vehicles	6,480	
	Sensor Repair / Replacement	25,920	
Demobilization			**13,723**
	53' Trailer Rental / Amortization	800	
	Trailer Tranporation	3,500	
	Base Camp Connex Pick Up	297	
	Facilities Pick Up	108	
	Unpacking of Trailer / Cleanup	6,588	
	Team Travel from Site	2,430	
Preparation and Reporting			
	Planning Meetings	7,200	**36,004**
	Demonstration Preparation	10,206	
	Demonstration Plan Preparation	9,299	
	Demonstration Data Report Preparation	9,299	
Data Reduction / Analysis			**40,743**
	Data Analyst Travel	1,620	
	Data Analyst	20,412	
	Data Analyst Per Diem	3,402	
	Data Reduction to Anomaly Lists	15,309	
Grand Total			**202,427**

Table 5-2 – Demonstration Time and Cost by Sensor System

Sensor System	Days for Data Collection	Data Collection Cost (k$)	Days for Data Analysis	Data Analysis Cost (k$)	Total Number of Days	Total Data Collection Cost (k$)
Magnetometer	2.0	18.4	2.5	10.5	4.5	28.9
EM61 MkII	4.5	41.4	2.5	10.5	7.0	51.9
GEMTADS	3.8	34.9	4.7	19.7	8.5	54.7

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Appendix A. MTADS EM61 MkII Performance at the Standardized UXO Technology Demonstration Sites

The Chemistry Division of the Naval Research Laboratory has participated in several programs funded by SERDP and ESTCP whose goal has been to enhance the discrimination ability of MTADS for both the magnetometer and EM-61 array configurations. The process was based on making use of both the location information inherent in an item's magnetometry response and the shape and size information inherent in the response to the time-domain electromagnetic induction (EMI) sensors that are part of the baseline MTADS in either a cooperative or joint inversion. As part of ESTCP Project 199812, a demonstration was conducted on a live-fire range, the 'L' Range at the Army Research Laboratory's Blossom Point Facility [4]. In 2001, a second demonstration was conducted at the Impact Area of the Badlands Bombing Range, SD [5] as part of ESTCP Project 4003. In all these efforts, our classification ability has been limited by the information available from the time-domain EMI sensor. The EM61 is a time-domain instrument with either a single gate to sample the amplitude of the decaying signal (MkI) or four gates relatively early in time (MkII). The first generation of the MTADS EM61 MkII array was demonstrated in 2001 [5] at the Badlands Bombing Range, SD with little demonstrable gain over the single decay of the MkI array. A second generation of the MkII array with updated electronics was constructed in 2003 as part of ESTCP Project 200413.

The upgraded MTADS EM61 MkII array was demonstrated at both of the Standardized UXO Technology Demonstration Sites located at the Aberdeen and Yuma Test Centers in 2003 and 2004 [6]. At each of the sites, the Calibration Lanes, the Blind Test Grid (if available), and as much of the Open Field Area as was possible were surveyed. The scoring results are the basis for characterizing the success of the demonstrations and the performance of the array. The Open Field results are presented here to demonstrate the performance of the MTADS EM61 MkII Array.

A.1 Aberdeen Proving Ground Open Field

Selected results from our surveys at the Open Field at the Aberdeen Proving Ground Standardized Test Site have been provided to us by analysts at the Institute for Defense Analyses. These results are summarized graphically in the following sections.

A.1.1 Response Stage

Response stage results for the APG Open Field scenario are shown in Figure A-1 and Figure A-2. The results are analyzed by excluding first items that were not covered by the survey or are within 2-m of another item then retaining those exclusions and further excluding items deeper than 11x their diameter.

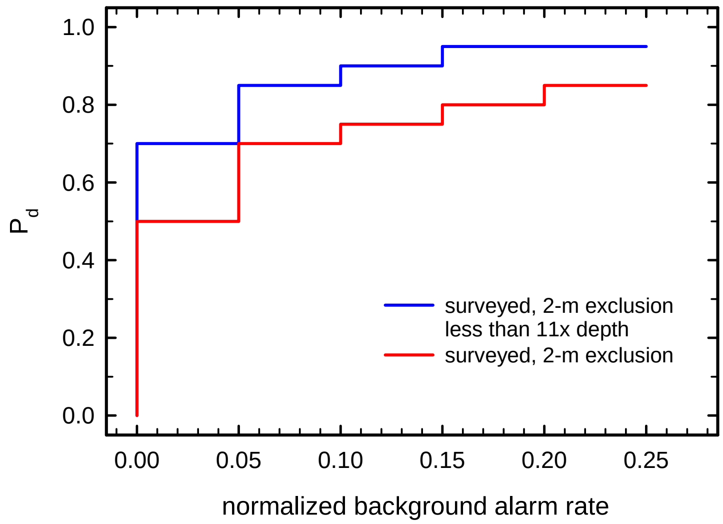

Figure A-1 – MTADS EM61 MkII detection performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

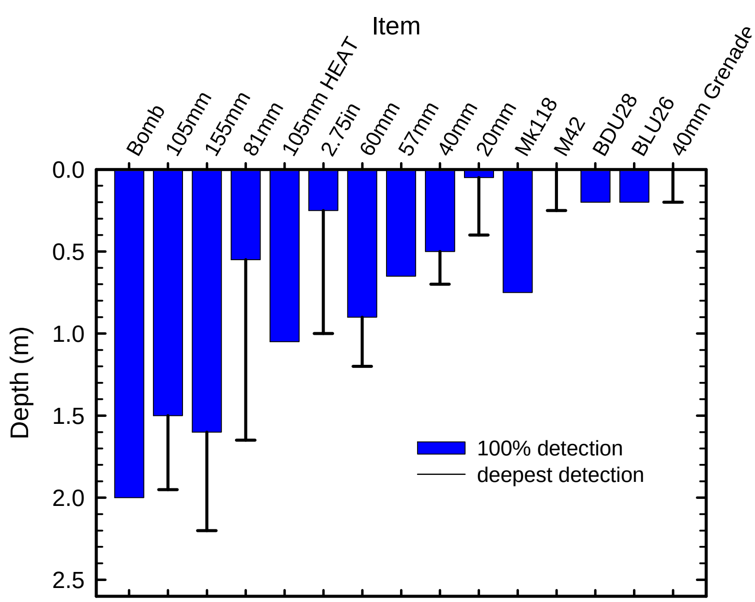

Figure A-2 – MTADS EM61 MkII response stage results for the APG Open Field scenario broken out by target type

A.1.2 Discrimination Stage

Discrimination Stage results from the APG Open Field are shown in Figure A-3. Exclusion of items that are deeper than 11x their diameter improves performance.

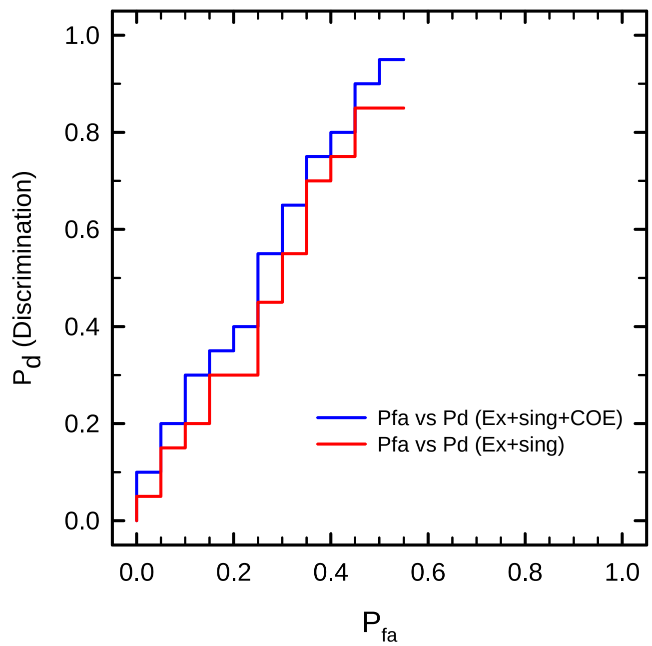

Figure A-3 – MTADS EM61 MkII discrimination performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

Appendix B. GEMTADS Performance at the Standardized UXO Technology Demonstration Sites

The NRL GEMTADS array was developed under ESTCP Project MM-0033. The project objective was to demonstrate the optimum system built around the Geophex GEM-3 EMI sensor that delivers the most classification performance while retaining acceptable survey efficiency. A three-sensor array system was designed around a modified GEM-3 sensor. The system was built and characterized and then demonstrated at the Standardized UXO Demonstration sites at Aberdeen Proving Ground and Yuma Proving Ground. At each of the sites, the Calibration Lanes, the Blind Test Grid, and as much of the Open Field Area as was possible were surveyed. For the Blind Test Grid and the Open Field, the ranked target picks were submitted to Aberdeen Test Center for scoring. These scoring results are the basis for characterizing the success of the demonstrations and the performance of the array. Portions of Reference 7 are reproduced here to summarize the performance of the system.

B.1 Aberdeen Proving Ground Blind Grid

B.1.1 Response Stage

The first stage of scoring at the Test Sites is the Response Stage where anomalies are identified, or detected. For this, we use the Q_{avg} quantity; the average of the quadrature response for the middle five frequencies.

$$Q_{avg} = \frac{\sum(Q_{270Hz} + Q_{570Hz} + Q_{1230Hz} + Q_{2610Hz} + Q_{5430Hz})}{5}$$

We choose this metric because of the lower noise in the quadrature response and the good signal in the mid frequencies for the objects of interest. A Q_{avg} plot for the APG Blind Grid is shown in Figure B-1. The 400 cells in the Blind Grid are marked with white squares in Figure B-1. A summary of the GEM array detection performance is given in Table B-1.

Table B-1 – Summary of Detection Performance at the APG Blind Grid.

Cell Contents	Number of Cells	Number Correct	Number Incorrect
Single Ordnance Item	84	73	11
Ordnance Item with Clutter	7	7	0
Single Clutter Item	95	91	4
Two Clutter Items	8	8	0
“Empty”	206	174	32
Total	**400**		

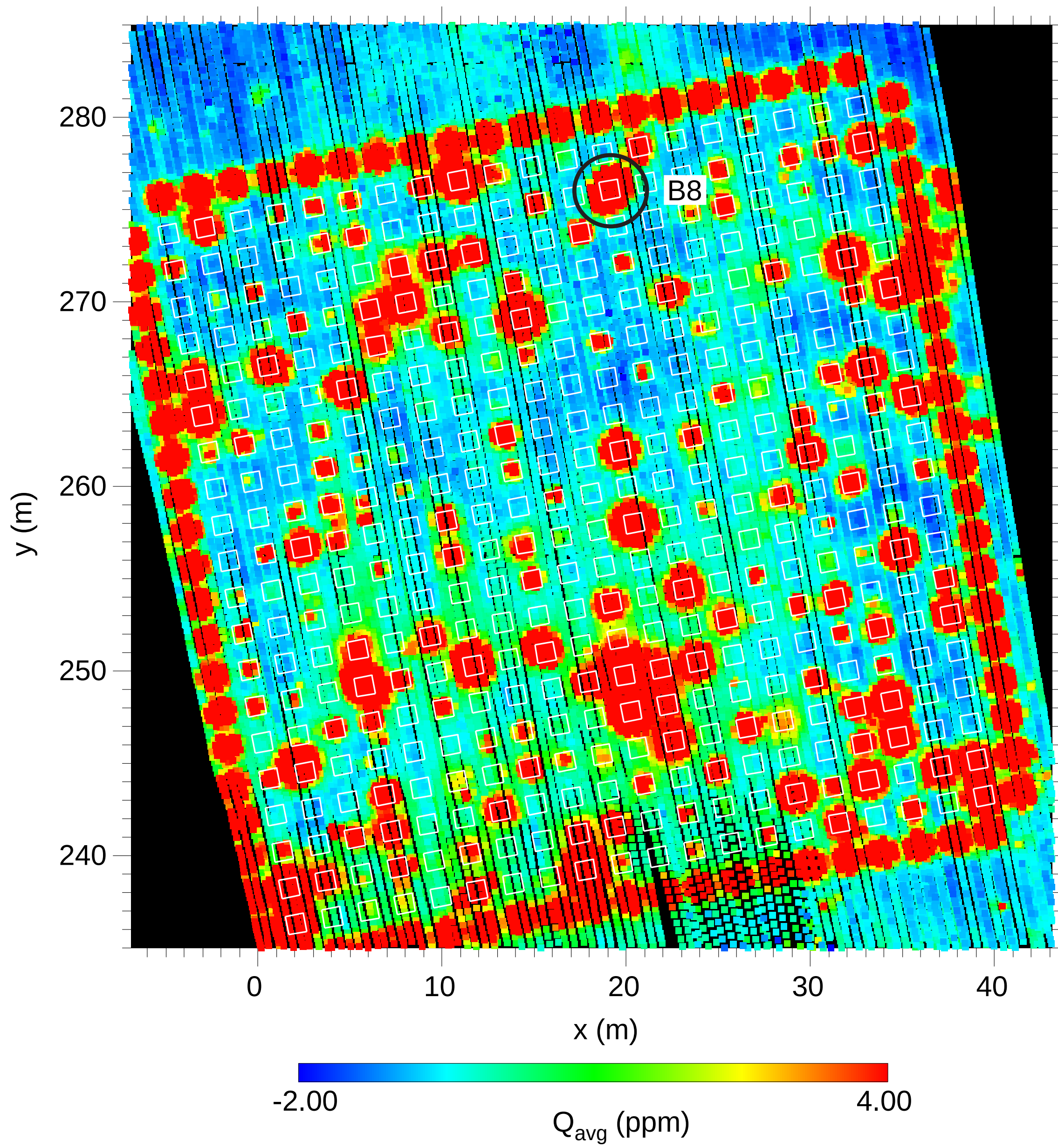

Figure B-1 – Q_{avg} anomaly image map of the APG Blind Grid

The 32 cells reported as "Empty" but for which we made a declaration require some discussion. Only 12 of these false positives showed signal in the GEM array survey only. Seven of these cells had a detection by the GEM array, the EM61 HH, and the magnetometer array. Ten had a detection by the GEM array and the EM61 HH and 3 had a detection by the GEM array and the magnetometer array. An example of this is cell B8 which is highlighted in Figure B-1. It is difficult to understand the observed signal unless there is some inadvertent metal in this cell.

An indication of the depth performance of the system is shown in Figure B-2. The detected items are shown as black triangles and the missed items are shown as red crosses. The reference line corresponds to a depth of 11x the item diameter. As can be seen, the GEM array is capable of detecting targets down to and below 11 times their diameter at this site.

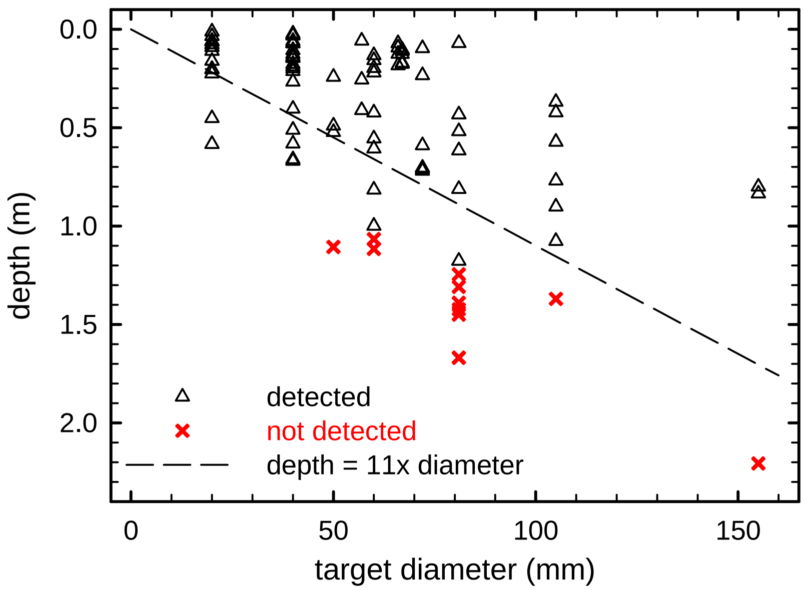

Figure B-2 – Q_{avg} Detection performance as a function of depth at the APG Blind Grid

The response stage data are plotted in Figure B-3 and Figure B-4 in the manner of the Standardized Test Site scoring reports. Figure 21 shows cumulative ordnance count vs. cumulative clutter count. Since the targets are ordered by signal amplitude at the response stage it is no surprise that this plot is essentially along the diagonal.

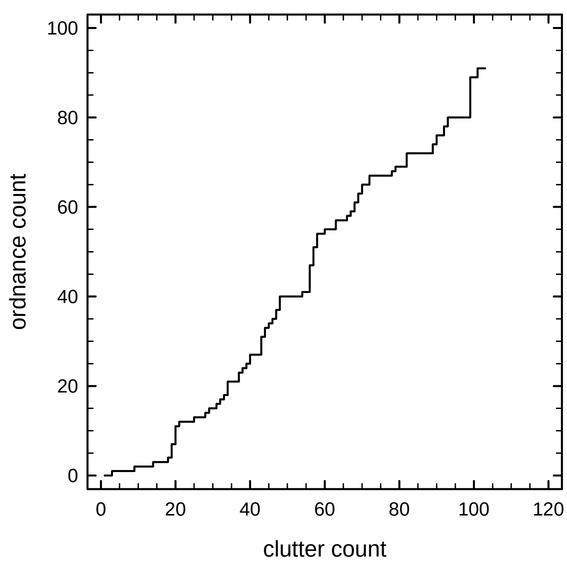

Figure B-3 – Response stage results showing cumulative ordnance count vs. cumulative clutter

A better measure of system capability is shown in Figure B-4 which plots cumulative occupied cells vs. adjusted cumulative blank cells. Cells such as B8 which obviously contain buried metal were excluded from the blank count.

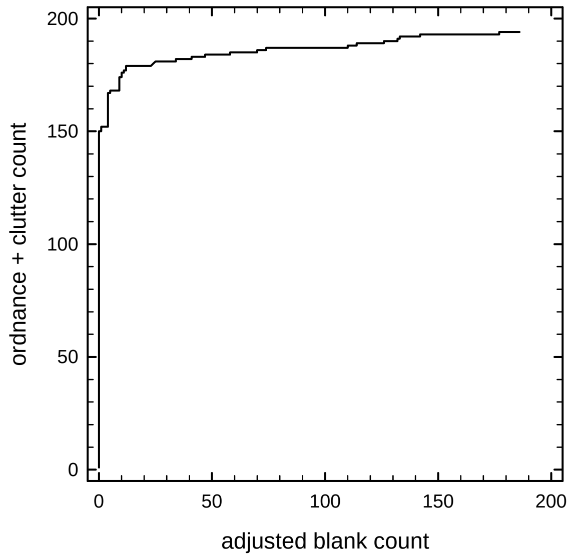

Figure B-4 – Response stage performance showing cumulative occupied cell count plotted vs. adjusted cumulative blank cell count

B.1.2 Discrimination Stage

The prescription for discrimination using GEMTADS is to compare the measured response of a target to each of a set of library response functions in turn, and to determine which library item results in the closest match to the target. If the match is good enough, we can declare the target as being that member of the library. To quantify the "goodness-of-fit" do this, we compute the χ^2 for the each match. For the APG Blind Grid, three different methods of discrimination based on the χ^2 were evaluated.

The first method is one based on the weighing of the χ^2 by the signal amplitude. If the signal level for the various targets differs by a large amount (some targets quite shallow and some very deep) the computed χ^2 can be strongly affected by the signal amplitude. To test this possibility, we computed the χ^2 for the best match weighting the data by the usual 1/rms^2 (where the rms deviation is determined from areas between targets) and by 1/(rms + 0.01 x signal) in an attempt to reduce the influence of depth on the computed χ^2. The χ^2 calculated with the signal-based weighting was used for our declarations at the APG Blind Grid. Based on the results from the Calibration Lanes (which was all we had available at the time), we established a χ^2 threshold of 0.01 for the ordnance/clutter decisions. This is a little less than three standard deviations above the ordnance mean. The reported Discrimination Response Factor was just the inverse of the χ^2.

The second method assumes that this strong variation of χ^2 with signal amplitude arises from the bouncing motion of the sensor array as it traverses the rough field. Over a high-signal target, small variations in *z* result in relatively large variations in signal as compared to over a deep, low-signal target. In this case, we can model the bouncing noise by (K * signal) and the correct weighting would be $1/(rms^2 + (K * signal)^2)$. Based on data collected on the Blossom Point Test Field, at values of K around 0.3, the scaling of χ^2 with signal amplitude seems to flatten out.

Scaling the weights by the signal improves the performance of the discrimination but is not very practical as the scaling coefficient is determined after the fact. For the later YPG and APG Open Field demonstrations we employed another method to mitigate the effects of bouncing noise. Each target was fit using a full, unconstrained 3-β model as well as the library model. The ratio of the χ^2 for these two methods, which eliminates the dependence on signal amplitude, should approach 1 if the item is in the library.

The ROC curves for the application of these three discrimination methods to the APG Blind Grid are shown in Figure B-5 through Figure B-7. The standard χ^2 weighting (Figure B-5) and the modified weighting with "bounce noise" added (Figure B-6) result in curves that vary little from the chance diagonal. There are fewer items in Figure B-6 than in Figure B-5. The original submission to APG required that a discrimination score be included for all cells, even those below our detection threshold. We arbitrarily assigned these cells a low discrimination score. The χ^2 with "bouncing noise" analysis was only applied to cells in which we declared a detection.

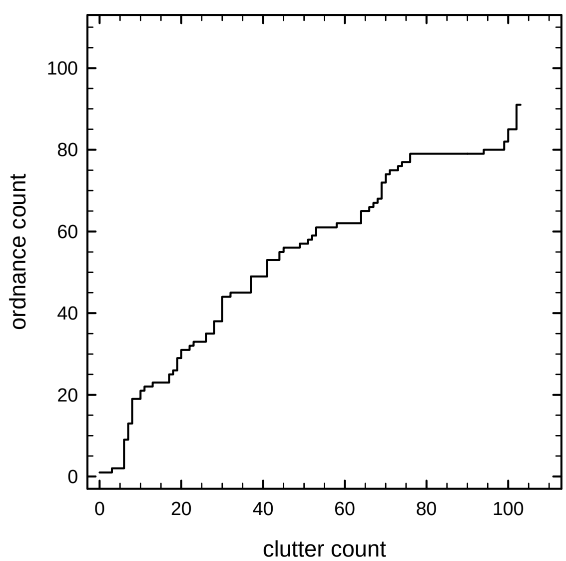

Figure B-5 – ROC curve for the χ^2 weighting applied to the APG Blind Grid as shown in the left-hand side of Figures 25 and 26 of Reference 7

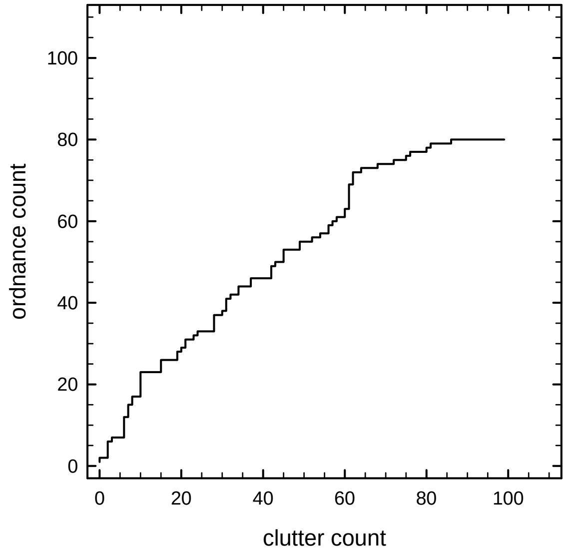

Figure B-6 – ROC curve for the case of χ^2 weighting with an estimate of "bouncing noise" included applied to the APB Blind Grid

The χ^2 ratio method (Figure B-7) does show some promise. Notice, however, that the curve in Figure B-7 includes even fewer ordnance and clutter items than in Figure B-6. The χ^2 ratio method requires two different inversions to converge to sensible results in order to calculate the ratio. As the signal-to-noise ratio decreases, this becomes an increasingly difficult hurdle. Library methods such as this can work well when the expected targets are well defined but can provide inappropriate results when a munitions item not in the library is encountered.

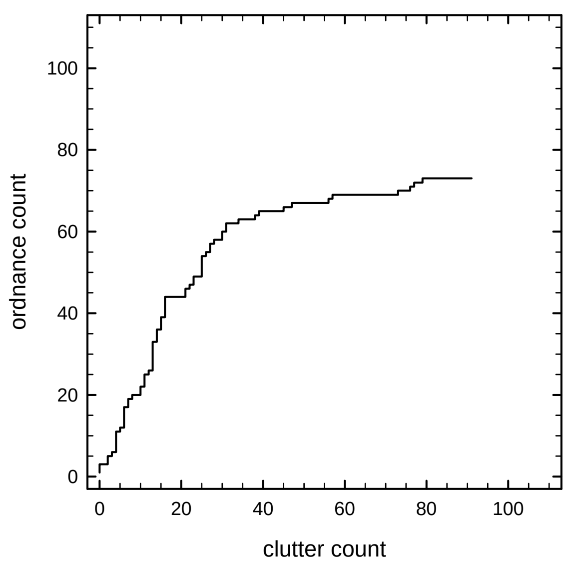

Figure B-7 – ROC curve for the χ^2 ratio method applied to the APG Blind Grid

B.2 Aberdeen Proving Ground Open Field

Selected results from our surveys at the Open Field at the Aberdeen Proving Ground Standardized Test Site have been provided to us by analysts at the Institute for Defense Analyses. These results are summarized graphically in the following sections.

B.2.1 Response Stage

Response stage data from the Open Field scenario at the APG Standardized Test Site is shown in Figure B-8 as a plot of probability of detection vs. normalized background alarm rate. There are two analysis models shown on the plot. The first, the red line, corresponds to considering only those targets that were covered by the survey and are not within 2 m of another target. The analysis corresponding to the blue line retains those limitations and also excludes those targets deeper than 11x their diameter. We showed in Figure 20 of Reference 7 that the GEM array demonstrated is able to detect small and medium targets below this relative depth but our detection efficiency falls off at depths below 11x the item diameter. Response stage results broken out by item type are shown in Figure B-9. In this figure, the depth of 100% detection is denoted by the blue bar and the depth of maximum detection is shown as the horizontal line. For a number of the items, 105-mm HEAT for example, these two depths are the same. For the majority of the items, the maximum depth of detection is below the depth of 100% detection.

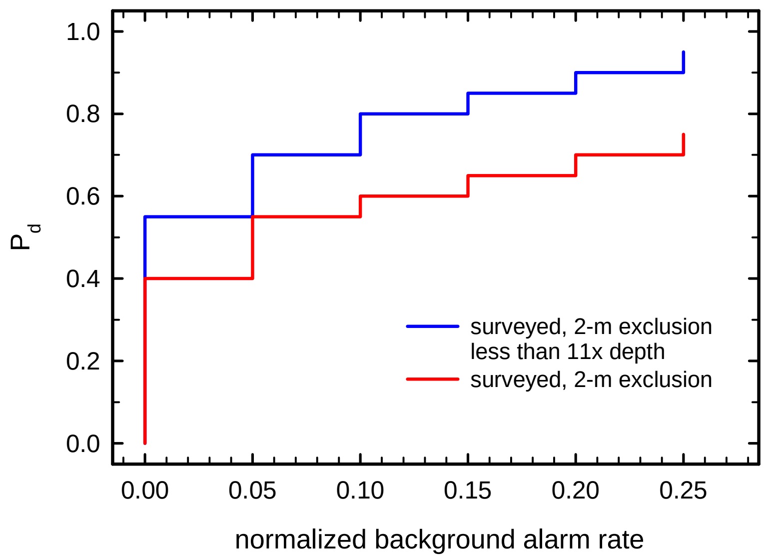

Figure B-8 – Detection performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

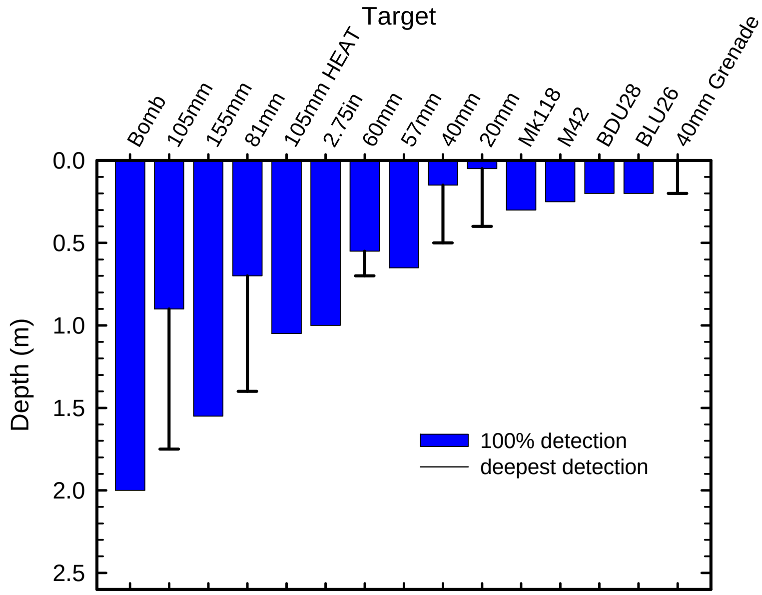

Figure B-9 – Response stage results for the APG Open Field scenario broken out by target type

B.2.2 Discrimination Stage

Discrimination stage performance at the APG Open Field using the same two analysis models is shown in Figure B-10. As above, the exclusion of items at depths below 11x their diameter (presumably lower S/N anomalies) improves the discrimination performance obtained.

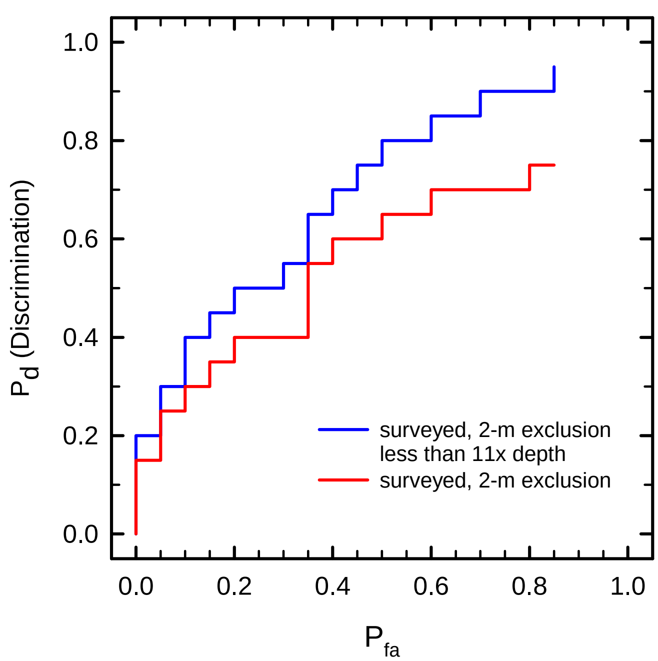

Figure B-10 – Discrimination performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

B.3 Yuma Proving Ground Open Field

Selected results from our surveys at the Open Field at the Yuma Proving Ground Standardized Test Site have been provided to us by analysts at the Institute for Defense Analyses. These results are summarized graphically in the following sections.

B.3.1 Response Stage

Response stage results for the YPG Open Field scenario are shown in Figure B-11 and Figure B-12. As for APG, they are analyzed by excluding first items that were not covered by the survey or are within 2-m of another item then retaining those exclusions and further excluding items deeper than 11x their diameter. Notice that the background alarm rates in Figure B-11 are more than a factor of two smaller than the corresponding results from Aberdeen. Although the Yuma site is more geologically active than Aberdeen, it is smoother so there were fewer false alarms due to platform bouncing over deep ruts. Detection depths at Yuma are, in general, in line with those obtained at Aberdeen. Note however, that a shallow bomb was apparently missed resulting in an unusual plot for that target type.

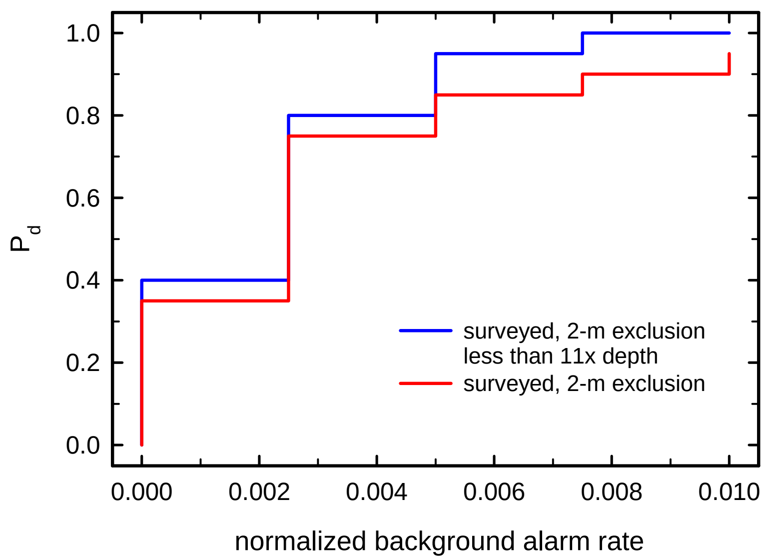

Figure B-11 – Detection performance at the YPG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

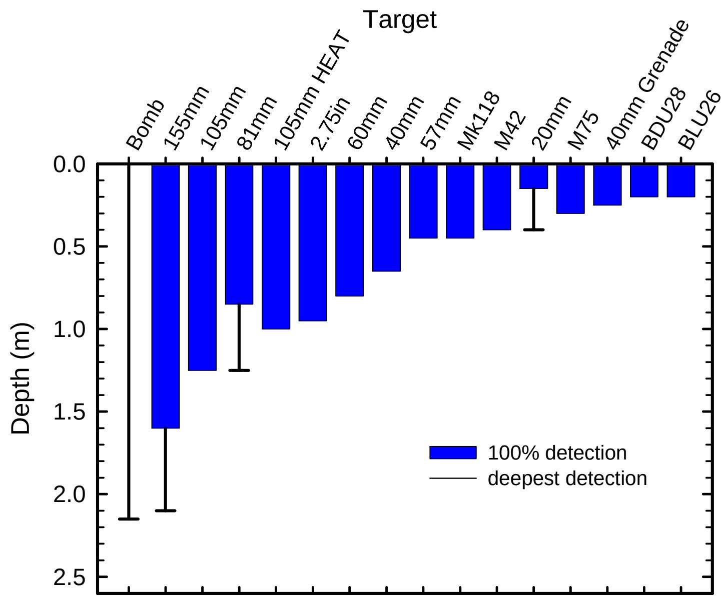

Figure B-12 – Response stage results for the YPG Open Field scenario broken out by target type

B.3.2 Discrimination Stage

Discrimination Stage results from the YPG Open Field are shown in Figure B-13. As before, exclusion of items that are deeper than 11x their diameter improves performance which is better, on the whole, than that observed at Aberdeen. As with the response stage, this is likely due to the lower platform motion noise observed at the Yuma site.

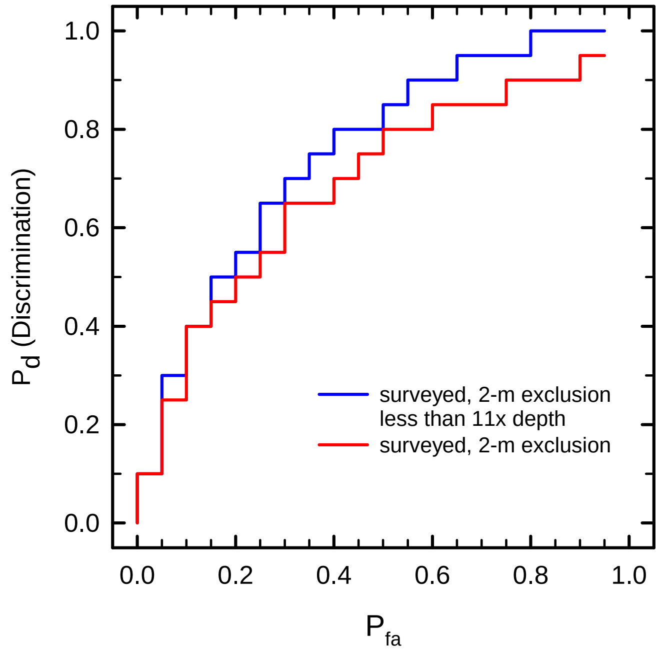

Figure B-13 – Discrimination performance at the YPG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

Appendix C. Quality Assurance Project Plan (QAPP)

C.1 Purpose and Scope of the Plan

The collection and archiving of high quality survey data in auditable and defensible manner is critical to insure the credibility of the data collected and to support decisions based in part or in total on that data. This Appendix outlines the standard process used in the NRL MTADS program to collect survey data, conduct quality checks to insure the quality of the data, and then process and archive the data. With the exception of Section C.9, the discussion focuses on the magnetometer array system. For the EM61 MkII and GEMTADS sensor systems similar procedures are used, different only in the details of the data collected for each sensor system. Any sensor platform unique items are indicated where appropriate.

C.2 Quality Assurance Responsibilities

The team as a whole is involved in insuring the quality of collected data. The MTADS has been designed to provide a series of visual indicators to the operator regarding the status of the individual subsystems that comprise the MTADS. The operator is responsible for monitoring these indicators and halting data collection immediately if any problems are indicated. The issue will be resolved prior to resuming operations. All team members are involved in visual walk-around inspections of the system at least daily. For each survey file set, the data preprocessing tasks are logging receipt of the file set, archiving the file set, verifying that all files within the file set are valid, and verifying that each sensor channel contains valid data with sufficient SNR (where appropriate). Any section of data which is found lacking is flagged accordingly and not processed any further. The section will be logged for future re-acquisition if necessary. The data analyst is responsible for the data preprocessing and processing tasks with the site / project manager’s assistance as available. Dr. Daniel Steinhurst will serve as the Quality Assurance Officer for this project.

C.3 Data Quality Parameters

Incoming survey data will be evaluated for: completeness of the data set, location quality for the data set, and for proper operation of the magnetometer sensors. The following section details in an example how the data quality issues are addressed throughout the survey.

C.4 Calibration Procedures, Quality Control Checks, and Corrective Action

The following procedure constitutes a typical startup for the MTADS system for both initial startup and as daily system evaluations. The RTK GPS base station receiver and radio link will be established on one of the established control points. The validity of the control point location will be verified using the MTADS man-portable RTK GPS rover receiver to occupy one or more of the established control points using the control point occupied by the GPS base station as a reference as required by the QAO.

For the GEMTADS array, the standard performance checks include three types of measurements. Initial system startup, at the beginning of field work and again each morning, consists of three measurements. First, quiet, static data are collected for a period (15 - 20 minutes or as directed by the QAO) with all systems powered up and warmed up (typically 30 minutes). Next, two calibration items, a 4” diameter Aluminum (Al) sphere and a ferrite rod bundle, are placed a standard distance above the center of each sensor coil several times in sequence to verify the response of each sensor to each object. The system is stationary for this data collection. Finally, a systems timing check using a fixed-position wire or chain placed on the ground is conducted. At the discretion of the QAO, the timing check may be repeated in the middle of the survey day. At the discretion of the QAO, the timing check and the Al sphere and ferrite measurements may be repeated at the end of the day.

For the EM61 MkII array, the standard performance checks are the same as for the GEMTADS with the ferrite rod measurements deleted. The ferrite rod is not a useful calibration item for this time-domain instrument. For the magnetometer array, the Al sphere measurements are also deleted and the quiet period is reduced to 5-10 minutes. Each sensor platform’s performance check requirements are based on data rates and the historical stability and reproducibility of each sensor type.

A survey of the emplaced calibration items will be conducted and repeated at the beginning and end of each work day and as required by the QAO. Data will be digitally recorded and submitted to the Data Analyst. The data will be checked for appropriate signal strength and noise levels immediately, and inverted in post processing to verify consistency of parameter estimation. When all system checks are completed to the satisfaction of the QAO, the main survey will commence.

Preventative maintenance inspections will be conducted at least once a day by all team members, focusing particularly on the tow vehicle and sensor trailer. Any deficiencies will be addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios are available in the system spares inventory which will be on site. Status on any break-downs / failures which will result in long-term delays in operations will be immediately reported to a representative of the Program Office.

MTADS survey raw data generally falls into two categories, location and magnetometer sensor measurements. The data set is comprised of ten separate files, each containing the data from a single system device. Each device has a unique data rate. A software package written by NRL examines each file and compares the number of entries to the product (total survey time * data rate). Any discrepancies are flagged for the data analyst to address. For magnetometer sensor data, operational values are typically on the order of 50,000 nT and have noise levels of ~0.5 nT peak-to-peak (PP) static and 3-5 nT PP in motion. Sensor “drop-outs” can occur if the sensor is tilted out of the operation zone with respect to the earth’s magnetic field. If a sensor cable is severed or damaged while in motion, the sensor output value will drop below 20,000 nT and/or become very noisy (1,000’s of nT PP). All magnetometer sensor channels (8 total) are examined in each survey file set for these conditions and any data which is deemed unsatisfactory is flagged and not processed further. For location data, the RTK GPS receivers present a Fix Quality value that relates to the quality / precision of the reported position. A Fix Quality (FQ) value of 3 (RTK Fixed) is the best accuracy (typically 3-5 cm or better). A FQ value of 2 (RTK Float) indicates that the highest level of RTK has not be reached yet and location accuracy can be degraded to as poor as ~1 m. FQ 1 & 4 correspond to Autonomous and DGPS operational modes respectively. Data collected under FQ 3 and FQ 2 (at the discretion of the data analyst) are retained. Any other data are deemed unsatisfactory, flagged and not processed further. The Survey section containing the flagged data will be logged for future re-acquisition if required. Data which meet these standards are of the quality typical of the MTADS system.

Note that for the EM61 MkII and GEMTADS arrays, the orientation of the platform is also recorded as described in Section 2. Two additional GPS strings of the “PTNL, AVR” type are recorded and the output of the IMU is also recorded. Similar quality checks are applied to these data as for the magnetometer system.

C.5 Demonstration Procedures

See Section C.4. The same discussion applies to this section.

C.6 Calculation of Data Quality Indicators

There are no specialized equations required. The methods are outlined in Section C.4.

C.7 Performance and System Audits

See Section C.4. The same discussion applies to this section.

C.8 Quality Assurance Reports

The results of the daily system checkout runs for the standard systems checks and the dynamic survey of the emplaced items will be reported to the QAO daily. The Data Analyst will report any data sections requiring reacquisition to the site / project manager for a given day by the start of work the following morning.

C.9 Data Formats

C.9.1 Magnetometer Array

Each survey file set contains 10 files which constitute the ‘raw data’. The file name structure is YYDDDFFF.DeviceType.DeviceAlias; where YY is the 2-digit year, DDD is the "Julian" day, or day in the year, and FFF is the flight number starting with 001. In the following example, the data was taken on the 210th day of 2002, flight number 4.

02210004.Survey.822A.822A_1
02210004.Survey.822A. 822A_2
02210004.Survey.GPS.NMEA
02210004.Survey.SerialDevice.UTC
02210004.Survey.PpsDevice.PPS
02210004.Survey.TriggerDevice.Trigger
02210004.Survey.LineNumber
02210004.Survey
02210004.Survey.page
02210004.Survey.loginfo1.txt

Each data line is time stamped with the PC system clock to allow synchronization between files

YYDDDFFF.Survey.LineNumber - start and stop time of each line in survey, typically only one line / file
YYDDDFFF.Survey.822A.822A_1 - Output from Counter 1 (4 magnetometers), in nT x 10^5, 50 Hz.
YYDDDFFF.Survey.822A.822A_2 - Output from Counter 2 (4 magnetometers), in nT x 10^5, 50 Hz.
YYDDDFFF.Survey.PpsDevice.PPS - pulse per second (PPS) from GPS receiver, 1 Hz.
YYDDDFFF.Survey.GPS.NMEA - GPS output, Trimble PTNL,GGK sentence at 5 Hz (position).
YYDDDFFF.Survey.TriggerDevice.Trigger - trigger pulse to magnetometers, 50 Hz.
YYDDDFFF.Survey.SerialDevice.UTC - UTC time tag from GPS receiver, "The time will be" message for next PPS, 1 Hz.

The .Survey, .Survey.page, and .Survey.loginfo*.txt files are setup information recorded by the data collection program and contain no data of use to the user.

.Survey.LineNumber files:

```
START LINE 0  12/21/04 12:45:39.523
STOP  LINE 0   12/21/04 12:59:21.072
```

Magnetometer (.822A) files:

```
d15289543808d25289567673d35289555967d45289802122  10/10/02 14:17:00.508
d15289545560d25289568728d35289557064d45289803821  10/10/02 14:17:00.528
d15289547878d25289569235d35289557743d45289805162  10/10/02 14:17:00.548
d15289547468d25289568538d35289557255d45289804417  10/10/02 14:17:00.568
d15289546204d25289567936d35289556456d45289802950  10/10/02 14:17:00.588
d15289545018d25289566714d35289556217d45289801466  10/10/02 14:17:00.608
```

First line:
d1 - Sensor 1 ok - two characters of status code / marker - other two character codes are possible to indicate error conditions
`5289543808 - 52895.43808 gamma or nT`
d2 - Sensor 2 ok
`5289567673 - 52895.67673 nT`
d3 - Sensor 2 ok
`5289555967 - 52895.55967 nT`
d4 - Sensor 2 ok
`5289802122 - 52898.02122 nT`

`10/10/02` - computer date stamp for receipt of string at computer.
`14:17:00.508` - computer time stamp for receipt of string at computer.

.Survey.PpsDevice.PPS files:

```
PPS   12/21/04 12:45:40.433
PPS   12/21/04 12:45:41.433
PPS   12/21/04 12:45:42.433
```

.Survey.GPS.NMEA files:

```
$PTNL,GGK,175017.00,122104,3825.06336634,N,07706.26656042,W,3,07,2.8,EHT-
25.694,M*7C  12/21/04 12:45:39.470
```

Table C-1– PTNL,GGK Message Fields

Field	**Meaning**[a]
1	UTC of position fix
2	Date
3	Latitude
4	Direction of Latitude (N = North, S = South)
5	Longitude
6	Direction of Longitude (E = East, W = West)
7	GPS Fix Quality (0 = Invalid,1,2,3,4)
8	Number of Satellites in fix
9	DOP of fix
10	Ellipsoidal height of fix
11	M: ellipsoidal height is measured in meters

[a] For further information, refer to the Trimble MS Series Operation Manual

.Survey.SerialDevice.UTC files:

```
UTC 04.12.21 17:50:18 57  12/21/04 12:45:39.645
UTC 04.12.21 17:50:19 57  12/21/04 12:45:40.646
```

Located data archives are ASCII files of the format:

For located, demedianed magnetometer data:

```
X (UTM Zone X, NAD83, m) Easting
Y (UTM Zone X, NAD83, m) Northing
Z Height Above Ellipsoid (HAE, WGS84, m)
S Signal in nT
```

where X is the appropriate UTM zone (16N for Gadsden, AL)

Static Survey Archive (_static.xyz) files:
Daily static calibration run data will be archived as ASCII (.XYZ) files of the format:

```
X       (UTM Zone X, NAD83, m) Easting for GPS antenna
Y       (UTM Zone X, NAD83, m) Northing for GPS antenna
HAE     (WGS84, m) Height above Ellipsoid for GPS antenna
Mag1    (nT) Demedianed magnetometer data for sensor 1
Mag2    (nT) Demedianed magnetometer data for sensor 2
Mag3    (nT) Demedianed magnetometer data for sensor 3
Mag4    (nT) Demedianed magnetometer data for sensor 4
Mag5    (nT) Demedianed magnetometer data for sensor 5
Mag6    (nT) Demedianed magnetometer data for sensor 6
Mag7    (nT) Demedianed magnetometer data for sensor 7
```

```
Mag8    (nT) Demedianed magnetometer data for sensor 8
```

where X is the appropriate UTM zone (16N for Gadsden, AL)

MTADS DAS Anomaly Report Example

The example is given in ASCII text file format. Actual delivery will be in Excel Spreadsheet format.

```
MTADS TARGET REPORT
###################
Mon Oct 31 14:00:47 2005
PROJECT: PBR2
SITE: Area_2A
SENSOR: mag
SURVEY: Survey
PRIMARY COORDINATES: UTM=13, nad83
###################
###################
###################
###################
ID,UTM X (m),UTM Y (m),Depth (m),Size (m),Moment (Amps-
m2),Inclination,Azimuth,Goodness of Fit,Comments
1,617608.50,4176876.99,0.331,0.028,0.0121,26.70,30.32,0.9714,
2,617793.59,4176877.94,0.931,0.168,2.5717,57.71,10.09,0.9362,
3,617799.14,4176867.65,0.844,0.125,1.0476,55.00,24.48,0.9964,
```

C.9.2 EM61 MkII Array

Each survey file set contains 13 files which constitute the 'raw data'. The root filename structure is the same as for the magnetometer system. Each data line is time stamped with the PC system clock to allow synchronization between files

YYDDDFFF.Survey.GPS.GGK_AVR1
GPS output, Trimble PTNL,GGK sentence at 20 Hz (position), PTNL,AVR sentence for MB1 / MB2 receiver pair at 10 Hz (orientation).

YYDDDFFF.Survey.GPS.GGK_AVR2
GPS output, Trimble PTNL,AVR sentence for MB2 / MR receiver pair at 10 Hz (orientation).

YYDDDFFF.Survey.EM61MII.EM61_MkII_1
Output from Sensor #1 (Port), 4 time gates (counts), Transmit current (counts), and battery voltage (counts).

YYDDDFFF.Survey.EM61MII.EM61_MkII_2
Output from Sensor #2 (Center), 4 time gates (counts), Transmit current (counts), and battery voltage (counts).

YYDDDFFF.Survey.EM61MII.EM61_MkII_3
Output from Sensor #3 (Starboard), 4 time gates (counts), Transmit current (counts), and battery voltage (counts).

YYDDDFFF.Survey.GPS.GGK_AVR1
GPS output, Trimble PTNL,GGK sentence at 20 Hz (position), PTNL,AVR sentence for MB1 / MB2 receiver pair at 10 Hz (orientation).

YYDDDFFF.Survey.LineNumber
Start and stop time of each line in survey, typically only one line / file

YYDDDFFF.Survey.PpsDevice.PPS
Pulse per second (PPS) from GPS receiver, 1 Hz.

YYDDDFFF.Survey.SerialBinDevice.IMU
Output from IMU (pitch, roll, angular rates, accelerations, etc.) in packed binary format.

YYDDDFFF.Survey.SerialDevice.UTC

```
UTC time tag from GPS receiver MR, "The time will be" message for next PPS, 1 Hz.
```

The .Survey, .Survey.page, and .Survey.loginfo*.txt files are setup information recorded by the data collection program and contain no data of use to the user. The EM61 MkII and IMU data file formats are packed binary data formats with an ASCII date/time tag appended to each data packet. The data packet formats are described each manufacturer's manuals and technical notes and are not reproduced here.

.Survey.GPS.GGK_AVR1 files:

```
$PTNL,GGK,154409.65,010907,3251.14866418,N,11416.21512783,W,3,06,3.7,EHT120.6
47,M*67  01/09/07 15:33:36.583
$PTNL,GGK,154409.70,010907,3251.14866416,N,11416.21512781,W,3,06,3.7,EHT120.6
47,M*6F  01/09/07 15:33:36.633
$PTNL,AVR,154409.60,+285.3082,Yaw,+2.4128,Tilt,,,1.917,3,3.7,6*08  01/09/07
15:33:36.654
```

The AVR1 data file contains a redundant copy of the MB1 / MB2 PNTL,AVR message. The AVR2 files contains the MB2/MR PNTL, AVR message. The PTNL,AVR message format used in all files is given in Table C-2.

Table C-2 – PTNL,AVR Message Fields

Field	**Meaning**[a]
1	UTC of position fix
2	Yaw (degrees)
3	Yaw label
4	Tilt (degrees)
5	Tilt label
6	Reserved
7	Reserved
8	Range (meters)
9	GPS Fix Quality (0 = Invalid,1,2,3,4)
10	DOP of fix
11	Number of Satellites in fix

[a] For further information, refer to the Trimble MS Series Operation Manual

Located data archive files are in an ASCII format of the form:

For located, demedianed EM61 MkII data:

```
T                  (seconds) UTC time in seconds past midnight
X                  (UTM Zone X, NAD83, m) Easting for sensor
Y                  (UTM Zone X, NAD83, m) Northing for sensor
Z                  (WGS84, m) Height above Ellipsoid for sensor
COG                (degrees) Heading of array in DAS frame, East = 0 degrees
GPS_Pitch          (degrees) Pitch of the sensor platform as determined from
                   GPS array
```

GPS_Roll	(degrees) Roll of the sensor platform as determined from GPS array
IMU_Pitch	(degrees) Pitch of the sensor platform as determined from IMU
IMU_Roll	(degrees) Roll of the sensor platform as determined from IMU
Combined_Pitch	(degrees) Pitch of the sensor platform as determined from GPS and IMU
Combined_Roll	(degrees) Roll of the sensor platform as determined from GPS and IMU
SensorID	Denotes which sensor the data was recorded from
Gate1	(mV) Demedianed magnetometer data for first gate, bottom coil
Gate2	(mV) Demedianed magnetometer data for first gate, top coil
Gate3	(mV) Demedianed magnetometer data for second gate, bottom coil
Gate4	(mV) Demedianed magnetometer data for third gate, bottom coil
Voltage	Battery voltage reading from EM61 MkII console (Volts)
Current	Transmitter current reading from EM61 MkII console (Counts). 3,000 counts is Geonics baseline value
Filename	Filename of source data file

where X is the appropriate UTM zone (16N for Gadsden, AL)

Static Survey Archive (_static.xyz) files:
Daily static calibration run data are archived as Geosoft .XYZ files in the same format as the data archives.

UX-Analyze Anomaly Report Example

The Geosoft Oasis montaj add-in, UX-Analyze was used to analyze anomalies for the EM61 MkII data. The results are distributed as an Excel 2003 spreadsheet, but an excerpt is given in .csv format below for reference purposes.

```
Anomaly X,Anomaly Y,Grid_value,Fit_X,Fit_Y,Depth (m),Size (m),Fit
Quality,Beta 1,Beta 2,Beta 3,Phi (deg),Psi (deg),Theta
(deg),Fiducial,Fit_chi2,Comments
578835.50,3751636.50,80.00,578835.258,3751636.713,0.218,0.022,0.8567,0.0571,0
.0197,0.0132,113.76,-23.52,-16.87,2,93.2868,
578923.00,3751640.00,287.70,578923.078,3751639.830,0.317,0.027,0.9696,0.1576,
0.0015,0.0002,191.08,69.25,88.82,3,519.4497,
578832.00,3751640.50,4341.80,578832.086,3751640.547,0.227,0.085,0.9684,2.1290
,1.6593,1.1741,198.07,-83.36,-10.33,4,40874.5717,
578840.00,3751640.50,30.00,578840.222,3751640.339,0.004,0.012,0.5258,0.0098,0
.0038,0.0003,100.71,122.80,13.77,5,108.0199,
578855.50,3751642.50,206.10,578855.308,3751642.630,1.172,0.087,0.9540,3.9645,
0.8552,0.5093,298.90,-157.18,69.68,6,228.2829,
578871.50,3751642.50,26.50,578871.462,3751642.580,0.229,0.013,0.2900,0.0104,0
.0086,0.0000,11.66,-99.16,26.09,7,305.3852,
```

C.9.3 GEM-3 (GEMTADS) Array

Each survey file set contains eight files which constitute the 'raw data'. The file name structure is based on the date and time of the start logging event (MMMDDYYYY_HHMMSS). Data in each file is time stamped with the appropriate clock to allow synchronization between files. The information content of the GPS and IMU files is the same as for the EM61 MkII and the format details are not reproduced here. The detailed file format is slightly different due to differences between MagLogNT and WinGEM2kArr software packages.

MMMDDYYYY_HHMMSS.Survey.AVR1.csv
    GPS output, Trimble PTNL,GGK sentence at 20 Hz (position), PTNL,AVR sentence for MB1 / MB2 receiver pair at 10 Hz (orientation).
MMMDDYYYY_HHMMSS.Survey.AVR2.csv
    GPS output, Trimble PTNL,AVR sentence for MB2 / MR receiver pair at 10 Hz (orientation).
MMMDDYYYY_HHMMSS_ID1.Survey.GEM.csv
    Output from Sensor #1 (Port, Forward), In-phase and Quadrature data for 9 frequencies.
MMMDDYYYY_HHMMSS_ID2.Survey.GEM.csv
    Output from Sensor #2 (Center, Aft), In-phase and Quadrature data for 9 frequencies.
MMMDDYYYY_HHMMSS_ID3.Survey.GEM.csv
    Output from Sensor #3 (Starboard, Forward), In-phase and Quadrature data for 9 frequencies.
MMMDDYYYY_HHMMSS.Survey.PPS.csv
    pulse per second (PPS) from GPS receiver, 1 Hz.
MMMDDYYYY_HHMMSS.Survey.IMU.tbf
    Output from IMU (pitch, roll, angular rates, accelerations, etc.) in packed binary format.
MMMDDYYYY_HHMMSS.Survey.UTC.csv
    UTC time tag from GPS receiver MR, "The time will be" message for next PPS, 1 Hz.

The .Survey, .Survey.page, and .Survey.loginfo*.txt files are setup information recorded by the data collection program and contain no data of use to the user. The IMU data are recorded in a packed binary data format with a time tag appended periodically. The data packet format is described in the manufacturer's manuals and technical notes and is not reproduced here. The GEM-3 data files are well annotated internally and the format is not discussed here.

Located data archive files are in an ASCII file format of the form:

For located, demedianed GEM-3 data:

T	(seconds) UTC time in seconds past midnight
X	(UTM Zone X, NAD83, m) Easting for sensor
Y	(UTM Zone X, NAD83, m) Northing for sensor
Z	(WGS84, m) Height above Ellipsoid for sensor
COG	(degrees) Heading of array in DAS frame, East = 0 degrees
GPS_Pitch	(degrees) Pitch of the sensor platform as determined from GPS array
GPS_Roll	(degrees) Roll of the sensor platform as determined from GPS array
IMU_Pitch	(degrees) Pitch of the sensor platform as determined from IMU
IMU_Roll	(degrees) Roll of the sensor platform as determined from IMU

```
Combined_Pitch    (degrees) Pitch of the sensor platform as determined from
                  GPS and IMU
Combined_Roll     (degrees) Roll of the sensor platform as determined from
                  GPS and IMU
SensorID          Denotes which sensor the data was recorded from
90 Hz IP          (ppm) Demedianed GEM-3 data for 90 Hz, In-phase Response
90 Hz Q           (ppm) Demedianed GEM-3 data for 90 Hz, Quadrature Response
…

20010 Hz IP       (ppm) Demedianed GEM-3 data for 20,010 Hz, In-phase
                   Response
20010 Hz Q        (ppm) Demedianed GEM-3 data for 20,010 Hz, Quadrature
                   Response
Filename          Filename of source data file
```
where X is the appropriate UTM zone (16N for Gadsden, AL)

Static Survey Archive (_static.xyz) files:
Daily static calibration run data will be archived as geosoft .XYZ files in the same format as the data archives.

MTADS DAS Anomaly Report Example

The final format of the MTADS DAS output for the GEMTADS data is similar to that of the magnetometer and EM61 MkII systems. The results are distributed as an Excel 2003 spreadsheet, but the header is given in .csv format below for reference purposes.

```
ID,X (m),Y (m),Depth (m),Qave_Peak,RQ2,RI2,req (m),RQ2,RI2,,,Yaw ( o ),Pitch
( o ),Roll ( o ),DAS ID,GS ID,b1Q (90Hz),b1Q (150Hz),b1Q (270Hz),b1Q
(570Hz),b1Q (1230Hz),b1Q (2610Hz),b1Q (5430Hz),b1Q (11430Hz),b1Q
(20010Hz),b2Q (90Hz),b2Q (150Hz),b2Q (270Hz),b2Q (570Hz),b2Q (1230Hz),b2Q
(2610Hz),b2Q (5430Hz),b2Q (11430Hz),b2Q (20010Hz),b3Q (90Hz),b3Q (150Hz),b3Q
(270Hz),b3Q (570Hz),b3Q (1230Hz),b3Q (2610Hz),b3Q (5430Hz),b3Q (11430Hz),b3Q
(20010Hz),b1I (90Hz),b1I (150Hz),b1I (270Hz),b1I (570Hz),b1I (1230Hz),b1I
(2610Hz),b1I (5430Hz),b1I (11430Hz),b1I (20010Hz),b2I (90Hz),b2I (150Hz),b2I
(270Hz),b2I (570Hz),b2I (1230Hz),b2I (2610Hz),b2I (5430Hz),b2I (11430Hz),b2I
(20010Hz),b3I (90Hz),b3I (150Hz),b3I (270Hz),b3I (570Hz),b3I (1230Hz),b3I
(2610Hz),b3I (5430Hz),b3I (11430Hz),b3I (20010Hz),RQ2 (90Hz),RQ2 (150Hz),RQ2
(270Hz),RQ2 (570Hz),RQ2 (1230Hz),RQ2 (2610Hz),RQ2 (5430Hz),RQ2 (11430Hz),RQ2
(20010Hz),RI2 (90Hz),RI2 (150Hz),RI2 (270Hz),RI2 (570Hz),RI2 (1230Hz),RI2
(2610Hz),RI2 (5430Hz),RI2 (11430Hz),RI2 (20010Hz)
```

C.10 Data Storage and Archiving Procedures

Data are stored electronically as collected on the MTADS vehicle DAS computer hard drive. Approximately every two survey hours, the collected data are copied onto magnetic disks (Iomega ZIP 250) or removable media and transferred to the data analyst. The data are moved onto the data analyst's computer and the media is recycled. Raw data and analysis results are backed up from the data analyst's computer to optical media (CD-R or DVD-R) or external hard disks daily. These results are archived on an internal file server at NRL at the end of the survey. All field notes / activity logs are written in ink and stored in archival laboratory notebooks. These notebooks are archived at NRL. Relevant sections are reproduced in demonstration reports. Dr. Daniel Steinhurst is the POC for obtaining data and other information. His contact information is provided in Section 7 of this report.